AFRL-IF-RS-TR-1999-157
Final Technical Report
July 1999

DEMONSTRATION OF ATM-BASED ADVANCED AWACS NETWORK WITH INTEGRATED BATTLESPACE SIMULATION

The Boeing Company, Phantom Works

Jae H. Kim, Michael Y. Thompson, and Sankar Ray

APPROVED FOR PUBLIC RELEASE; DISTRIBUTION UNLIMITED.

AIR FORCE RESEARCH LABORATORY
INFORMATION DIRECTORATE
ROME RESEARCH SITE
ROME, NEW YORK

This report has been reviewed by the Air Force Research Laboratory, Information Directorate, Public Affairs Office (IFOIPA) and is releasable to the National Technical Information Service (NTIS). At NTIS it will be releasable to the general public, including foreign nations.

AFRL-IF-RS-TR-1999-157 has been reviewed and is approved for publication.

APPROVED: Richard C. Butler II

RICHARD C. BUTLER II
Project Engineer

FOR THE DIRECTOR:

WARREN H. DEBANY, JR., Technical Advisor
Information Grid Division
Information Directorate

REPORT DOCUMENTATION PAGE	*Form Approved* *OMB No. 0704-0188*

1. AGENCY USE ONLY *(Leave blank)*

2. REPORT DATE
July 1999

3. REPORT TYPE AND DATES COVERED
Final Aug 96 - Nov 98

4. TITLE AND SUBTITLE
DEMONSTRATION OF ATM-BASED ADVANCED AWACS NETWORK WITH INTEGRATED BATTLESPACE SIMULATION

5. FUNDING NUMBERS
C - F30602-96-C-0212
PE - 62702F
PR - 4519
TA - 22
WU - 43

6. AUTHOR(S)
Jae H. Kim, Michael Y. Thompson, and Sankar Ray

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
The Boeing Company,
Phantom Works
P.O. Box 3999, M/S 3W-51
Seattle WA 98124-2499

8. PERFORMING ORGANIZATION REPORT NUMBER
N/A

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)
Air Force Research Laboratory/IFGA
525 Brooks Road
Rome NY 13441-4505

10. SPONSORING/MONITORING AGENCY REPORT NUMBER
AFRL-IF-RS-TR-1999-157

11. SUPPLEMENTARY NOTES
Air Force Research Laboratory project engineer: Richard C. Butler/IFGA/(315) 330-1888

12a. DISTRIBUTION AVAILABILITY STATEMENT
Approved for public release; distribution unlimited.

12b. DISTRIBUTION CODE

13. ABSTRACT *(Maximum 200 words)*
Future C4I aircraft mission avionics suites will be required to handle a much greater aggregate data rate than is the case today, and also be required to provide a much more comprehensive set of network services to support on-board battle staffs. Current on-board networking technology cannot meet these emerging requirements.

Asynchronous Transfer Mode (ATM) networking technology has been identified as a significant potential backbone network for future mission avionics. ATM technology has been successfully demonstrated for some military applications, such as for fixed ground-based fiber networks, and the extension of this technology into the RF medium is currently under way with field demonstrations expected to take place very soon. For potential applications to airborne C4I, an ATM local-area network had been successfully demonstrated on Casey 01, but the demonstration did not include an operational scenario nor was it configured with a realistic C4I aircraft avionics suite. Thus, while ATM undoubtedly shows significant potential to meet on-board C4I network requirements, ATM network applicability and cost effectiveness for realistic C4I aircraft applications has to be fully implemented, quantitatively assessed, and operationally demonstrated. The objective of this program was to design, implement, assess, and demonstrate an ATM network in a realistic airborne C4I demonstration system (i.e., Advanced AWACS prototype).

14. SUBJECT TERMS
Asynchronous Transfer Mode (ATM), High-Speed Networking, Advanced C4I Aircraft, Mission Avionics, Airborne Networks, Advanced AWACS, EFX '98

15. NUMBER OF PAGES
152

16. PRICE CODE

17. SECURITY CLASSIFICATION OF REPORT	18. SECURITY CLASSIFICATION OF THIS PAGE	19. SECURITY CLASSIFICATION OF ABSTRACT	20. LIMITATION OF ABSTRACT
UNCLASSIFIED	UNCLASSIFIED	UNCLASSIFIED	UL

TABLE OF CONTENTS

LIST OF FIGURES iii

LIST OF ACRONYMS vi

1. INTRODUCTION 1

2. PROGRAM OBJECTIVE 2

3. PROGRAM SUMMARY 3

4. ATM-BASED ARCHITECTURE DEFINITION (TASK 1) 5
- 4.1. ATM Technology for AWACS Platform 5
- 4.2. AWACS Open System Architecture Network Requirements 5
- 4.3. Demonstration Systems Architecture Definition 6
- 4.4. ATM Multicast Solutions for AWACS Applications 9
  - 4.4.1. ATM Multicast Technology 9
  - 4.4.2. ATM Classical IP-Based Multicast Solution 9
  - 4.4.3. ATM LAN Emulation-Based Multicast Solution 10

5. ATM NETWORK IMPLEMENTATION (TASK 2) 13
- 5.1. ATM Switch and Analyzer Selection 13
- 5.2. AWACS-UAV-Fighter Platforms Selection 16
- 5.3. ATM Network Interface Cards Selection 16
- 5.4. ATM Network Implementation 17
  - 5.4.1. Parts List for ATM Implementation 19
  - 5.4.2. ATM Adapter Installation Procedure 21
  - 5.4.3. ATM Adapter Installation Problems 29
  - 5.4.4. ATM Adapter Installation Problems Fix 30

6. SYSTEM TEST AND PERFORMANCE EVALUATION (TASK 3) 32
- 6.1. ATM Switch, Interoperability, Application Program Test 32
  - 6.1.1. Switch Interoperability Test 35
  - 6.1.2. LAN Emulation BUS Throughput Test 37
  - 6.1.3. AWACS Program Run Test 40
- 6.2. ATM Multicast Configuration Test 42
  - 6.2.1. ATM LAN Emulation-Based Multicast Test 43
  - 6.2.2. ATM Classical IP-Based Multicast Test 46
- 6.3. ATM/FDDI Network Benchmark Test with AWACS Platforms 49
  - 6.3.1. Network Benchmark Test Tools 49
  - 6.3.2. TCP Performance Test 52

6.3.3. UDP Performance Test 62
6.3.4. Simultaneous TCP and UDP Performance Test 70

6.4. ATM/FDDI Application Benchmark Test with AWACS Programs 75
6.4.1. TCP Performance Test 75
6.4.2. Simultaneous TCP and UDP Performance Test 81

7. ATM-BASED AWACS SYSTEM DEMONSTRATION (TASK 4) 85

8. INTEGRATED BATTLESPACE SIMULATION (TASK 5) 87
8.1. AWACS-UAV-Fighter Subsystem Integration 88
8.2. Integrated Battlespace Simulation 89

9. AWACS NETWORK ARCHITECTURE TRADE STUDY (TASK 6) 93
9.1. ATM Alternatives 93
9.1.1. Fibre Channel Network 93
9.1.2. Gigabit Ethernet Network 95
9.1.3. Fast Ethernet Network 97
9.2. Architecture Choice of Existing AWACS Programs 98
9.2.1. US Advanced AWACS Open System Architecture 98
9.2.2. US AWACS Extend Sentry Step-1 Architecture 100
9.2.3. US Expeditionary Force Experiment AWACS Architecture 101
9.2.4. NATO AWACS Midterm Architecture 103
9.2.5. Australia AWACS Wedgetail Architecture 105
9.2.6. British NIMROD Architecture 106
9.3. Related Works on Wireless ATM 108
9.3.1. Wireless – Satellite ATM 109
9.3.2. Wireless – Terrestrial ATM 110
9.3.3. Wireless – Mobile ATM 111
9.3.4. Issues and Future Works 114

10. SUMMARY AND CONCLUSIONS 115

APPENDIX A: Data Exploitation, Mission Planning, and Communications System . 118

APPENDIX B: Published Paper in IEEE MILCOM'98 Conference Proceeding 120

APPENDIX C: Published Paper in IEEE Communications Letters (1999) 133

LIST OF FIGURES

Figure 3-1: Demonstration Process of ATM-Based Advanced AWACS Network
Figure 3-2: Interim and Final Demonstration Features
Figure 4.3-1: Existing Integrated Battlespace Simulation Demonstration System
Figure 4.3-2: Interim and Final Demonstration Systems
Figure 5.1-1: Performance Comparison of Multiple Vendors' ATM Switches
Figure 5.1-2: Performance Comparison of Multiple Vendors' ATM Analyzers
Figure 5.2: ATM Testbed for Integrated Battlespace Simulation
Figure 5.4: Workstation Architecture Components
Figure 5.4.1-1: Parts List for ATM Network Implementation
Figure 5.4.1-2: List of DEC Alpha-500 Workstations
Figure 5.4.1-3: List of DEC Alpha-600 Workstations
Figure 6.1: ATM LANE BUS Throughput Comparison
Figure 6.1.1: Switch Interoperability Test Configuration
Figure 6.1.2-1: Conceptual Diagram of LANE BUS Function
Figure 6.1.2-2: BUS Throughput Test Configuration
Figure 6.1.2-3: LANE BUS Throughput (Cisco ATM LAN Switch)
Figure 6.1.3: AWACS Program Run Test Configuration
Figure 6.2.1-1: ATM LAN Emulation Operation Concept
Figure 6.2.1-2: Multicast Configuration with Multiple ATM Emulated LANs
Figure 6.2.2-1: Classical IP over ATM Operation Concept
Figure 6.2.2-2: Multicast Configuration with Classical IP and PVCs
Figure 6.3.2-1(a): FDDI TCP Performance
Figure 6.3.2-1(b): ATM LANE TCP Performance
Figure 6.3.2-1(c): ATM CIP TCP Performance
Figure 6.3.2-2(a): FDDI TCP Performance
Figure 6.3.2-2(b): ATM LANE TCP Performance
Figure 6.3.2-2(c): ATM CIP TCP Performance
Figure 6.3.2-3(a): ATM LANE TCP Performance (by NTTCP)
Figure 6.3.2-3(b): ATM CIP TCP Performance (by NTTCP)
Figure 6.3.2-4(a): FDDI TCP Performance
Figure 6.3.2-4(b): ATM LANE TCP Performance
Figure 6.3.2-4(c): ATM CIP TCP Performance
Figure 6.3.2-5(a): FDDI TCP Performance
Figure 6.3.2-5(b): ATM LANE TCP Performance
Figure 6.3.2-5(c): ATM CIP TCP Performance
Figure 6.3.2-6(a): FDDI TCP Performance
Figure 6.3.2-6(b): ATM LANE TCP Performance
Figure 6.3.2-6(c): ATM CIP TCP Performance
Figure 6.3.2-7(a): FDDI TCP Performance
Figure 6.3.2-7(b): ATM LANE TCP Performance
Figure 6.3.2-7(c): ATM CIP TCP Performance

Figure 6.3.2-8(a): FDDI TCP Performance
Figure 6.3.2-8(b): ATM LANE TCP Performance
Figure 6.3.2-8(c): ATM CIP TCP Performance
Figure 6.3.3-1(a): FDDI UDP Performance
Figure 6.3.3-1(b): ATM LANE UDP Performance
Figure 6.3.3-1(c): ATM CIP UDP Performance
Figure 6.3.3-2(a): ATM LANE UDP Performance (by NTTCP)
Figure 6.3.3-2(b): ATM CIP UDP Performance (by NTTCP)
Figure 6.3.3-3(a): FDDI UDP Performance
Figure 6.3.3-3(b): ATM LANE UDP Performance
Figure 6.3.3-3(c): ATM CIP UDP Performance
Figure 6.3.3-4(a): FDDI UDP Performance
Figure 6.3.3-4(b): ATM LANE UDP Performance
Figure 6.3.3-4(c): ATM CIP UDP Performance
Figure 6.3.3-5(a): FDDI UDP Performance
Figure 6.3.3-5(b): ATM LANE UDP Performance
Figure 6.3.3-5(c): ATM CIP UDP Performance
Figure 6.3.3-6(a): FDDI UDP Performance
Figure 6.3.3-6(b): ATM LANE UDP Performance
Figure 6.3.3-6(c): ATM CIP UDP Performance
Figure 6.3.4-1(a): FDDI TCP and UDP Performance
Figure 6.3.4-1(b): FDDI TCP and UDP Performance
Figure 6.3.4-1(c): ATM LANE TCP and UDP Performance
Figure 6.3.4-1(d): ATM CIP TCP and UDP Performance
Figure 6.3.4-2(a): FDDI TCP Performance
Figure 6.3.4-2(b): ATM LANE TCP Performance
Figure 6.3.4-2(c): ATM CIP TCP Performance
Figure 6.3.4-3(a): FDDI TCP Performance
Figure 6.3.4-3(b): ATM LANE TCP Performance
Figure 6.3.4-3(c): ATM CIP TCP Performance
Figure 6.4.1-1: AWACS Application TCP Unicast Test over FDDI
Figure 6.4.1-2: AWACS Application TCP Unicast Test over ATM LANE
Figure 6.4.1-3: AWACS Application TCP Unicast Test over ATM CIP*
Figure 6.4.2-1: AWACS Application TCP and UDP Test over FDDI
Figure 6.4.2-2: AWACS Application TCP and UDP Test over ATM LANE
Figure 6.4.2-3: AWACS Application TCP and UDP Test over ATM CIP*
Figure 8.2-1: Integrated Battlespace Simulation Demonstration Scenario Map
Figure 8.2-2: Integrated Battlespace Simulation Demonstration Scenario Timeline
Figure 9.1.1: Fibre Channel Protocol Stacks
Figure 9.1.2: Gigabit Ethernet Protocol Stacks
Figure 9.2.1: Open System Architecture for Advanced AWACS
Figure 9.2.2: US AWACS Extend Sentry Step-1 Network Architecture
Figure 9.2.3-1: EOC Aircraft Architecture for EFX98 Demonstration
Figure 9.2.3-2: JFACC Aircraft Architecture for EFX98 Demonstration
Figure 9.2.3-3: AWACS Aircraft Architecture for EFX98 Demonstration

Figure 9.2.4:	NATO AWACS Midterm Network Architecture
Figure 9.2.5:	Wedgetail AWACS Mission System Network Architecture
Figure 9.2.6-1:	FDDI-Based TCS Computer Data Bus Architecture
Figure 9.2.6-2:	Alternative Fast Ethernet-Based Architecture
Figure 9.3.1:	ATM Satellite Network Simulation Testbed
Figure 9.3.3:	Simplified System Configuration of EFX98 Demonstration

LIST OF ACRONYMS

ATM	Asynchronous Transfer Mode
API	Application Programmable Interface
ARS	Address Resolution Server
ATO	Air Tasking Order
AWACS	Airborne Warning and Control System
BING	Bandwidth PING (see PING)
BSD	Berkeley Software Distribution
BUS	Broadcast and Unknown Server
CAP	Combat Air Patrol
DC	Display Console
DEMPC	Data Exploitation, Mission Planning, and Communications
DIS	Distributed Interactive Simulation
ELAN	Emulated LAN
FDDI	Fiber Distributed Data Interface
HCI	Human-Computer Interface
HEC	Header Error Control
IBS	Integrated Battlespace Simulation
ICMP	Internet Control Message Protocol
IETF	Internet Engineering Task Force
JFACC	Joint Force Air Component Commander
JSEAD	Joint Suppression of Enemy Air Defense
LANE	LAN Emulation
LEC	LAN Emulation Client
LECS	LAN Emulation Configuration Server
LES	LAN Emulation Server
MAC	Medium Access Control
MARS	Multicast Address Resolution Server
MC	Mission Computer
Netperf	Network performance monitoring tool
NTTCP	Network Trivial Transmission Control Protocol
OSA	Open System Architecture (Boeing Organization)
PVC	Permanent Virtual Circuits
PING	ICMP's common network monitoring tool
Pt-pt (pt-mpt)	Point-to-Point (Point-to-Multipoint)
RFC 1577	IETF's Document on "Classical IP and ARP over ATM"
SAR	Synthetic Aperture Radar
SVC	Switched Virtual Circuit
TCP	Transmission Control Protocol
UDP	User Datagram Protocol
UAV	Unmanned Aerial Vehicle
VLAN	Virtual LAN

1. INTRODUCTION

Future airborne command, control, communications, computing, and intelligence (C^4I) platforms, such as the advanced Airborne Warning and Control Systems (AWACS), may be required to support multiple high-resolution on-board sensors, equally high data rates from off-board sensors, an increased crew size with more complex consoles, and a sophisticated battle support analysis and highly interactive battle staff decision process. Therefore, future C^4I aircraft mission avionics suites will be required to handle a much greater aggregate data rate than is the case today, and also be required to provide a much more comprehensive set of network services to support on-board battle staffs. Current on-board networking technology cannot meet these emerging requirements.

Asynchronous Transfer Mode (ATM) networking technology has been identified as a significant potential backbone network for future mission avionics. ATM technology has been successfully demonstrated for some military applications, such as for fixed ground-based fiber networks, and the extension of this technology into the RF medium is currently under way with field demonstrations expected to take place very soon. For potential applications to airborne C^4I, an ATM local-area network had been successfully demonstrated on Casey 01, but the demonstration did not include an operational scenario nor was it configured with a realistic C^4I aircraft avionics suite. Thus, while ATM undoubtedly shows significant potential to meet on-board C^4I network requirements, ATM network applicability and cost effectiveness for realistic C^4I aircraft applications has to be fully implemented, quantitatively assessed, and operationally demonstrated.

2. PROGRAM OBJECTIVE

The objective of this program was to design, implement, assess, and demonstrate an ATM network in a realistic airborne C^4I demonstration system (i.e., Advanced AWACS prototype). This program supports realistic C^4I applications such as battlespace management, Synthetic Aperture Radar (SAR) signal processing and analysis, real-time Air Tasking Order (ATO) monitoring concepts. The demonstration system includes a suite of advanced C^4I applications and will be an integral component of an overall battlespace simulation activity. We accomplished the following basic goals: (1) implemented an ATM network for advanced AWACS systems, (2) developed a quantitative performance measure of ATM network technology, (3) demonstrated the integrated battlespace simulation over ATM network using a realistic airborne C^4I scenario, and (4) performed a wireless ATM trade study that includes the AWACS on-board and off-board network trade study. This program represents a significant step forward in the development of on-board network technology for future C^4I and similar aircraft, and in particular for the mission avionics suite of an advanced AWACS.

3. PROGRAM SUMMARY

The thrust of this program was to configure the existing prototype AWACS Open System Architecture (OSA) mission avionics system with an ATM network and demonstrate the integrated battlespace simulation using ATM-based AWACS prototype system for realistic C^4I applications. The advanced AWACS prototype is currently implemented with Ethernet and Fiber Distributed Data Interface (FDDI) networks. Key program milestones were an interim demonstration of the Advanced AWACS subsystem with ATM backbone networks and the final demonstration of integrated battlespace simulation including all three elements of the "sensor- C^4I-fighter" loop. The Advanced AWACS ATM network demonstration program flow is shown in Figure 3-1.

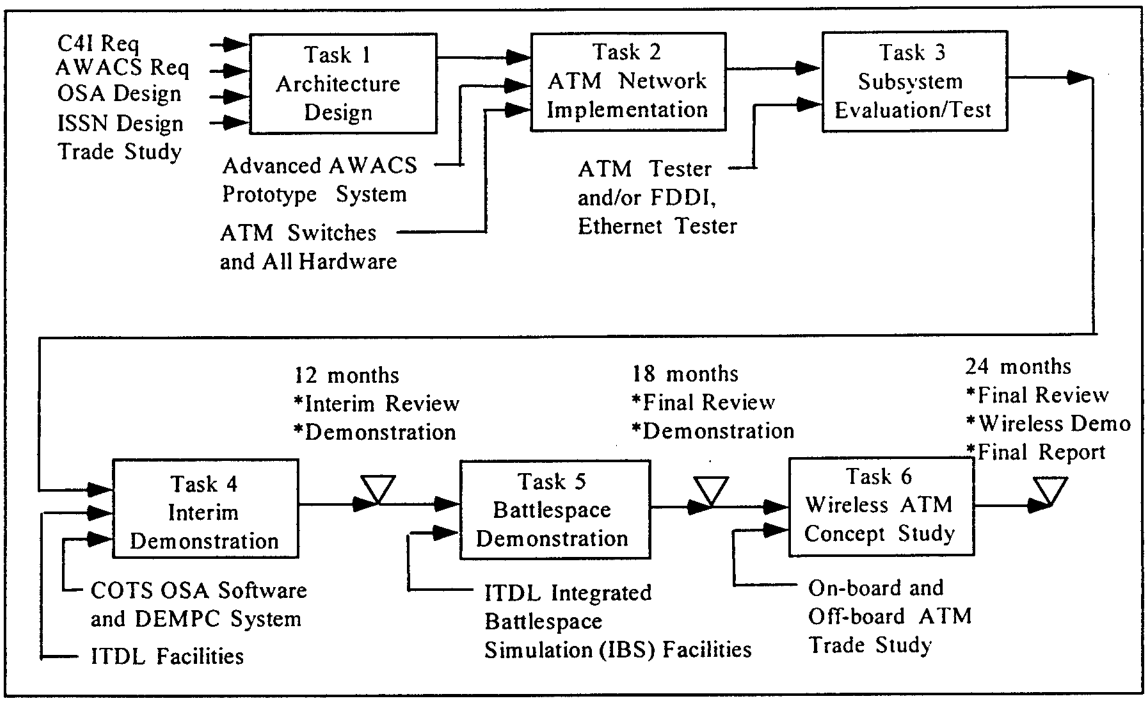


Figure 3-1: Demonstration Process of ATM-Based Advanced AWACS Network

Task 1: ATM-Based Architecture Definition

The current advanced AWACS OSA network incorporates legacy LANs, with separate 10Base-T Ethernet and FDDI providing backbone connectivity between the mission computer and display consoles and for external connectivity. These two separate networks were replaced with a single ATM network. The ATM-based network architecture was designed consistently with the OSA concept for Advanced AWACS.

Task 2: ATM-Based Network Implementation
The Commercial Off-The-Shelf (COTS) software and hardware (e.g., platforms, switches, network interface cards), based on the design study of Task 1, were evaluated, down-selected, acquired, and implemented into the Advanced AWACS prototype system.

Task 3: Subsystem Testing and Performance Evaluation
The performance evaluation test of the ATM-based systems was performed on both network and application levels. A set of application-specific performance criteria were established.

Task 4: Interim Laboratory Demonstration
The Advanced AWACS functionality was demonstrated over the ATM network. This interim demonstration relied on a pre-programmed AWACS application demonstration, including target simulations (over 1,000 targets), sensor returns from the simulated targets (e.g., Radar, IFF, ESM), and tracking processing (Figure 3-2).

Task 5: Integrated Battlespace Demonstration
The Advanced AWACS, UAV ground station, and advanced fighter are integrated onto ATM-based networks and are used for a realistic battlespace scenario demonstration.

Interim Demonstration	Final Demonstration
<u>Advanced AWACS Subsystem</u> • over 1,000 simulated targets • over 1,000 system tracks • up to 1,000 simulated sensor returns, e.g., radar, IFF, ESM	<u>Integrated Battlespace Simulation</u> • various types of sensor inputs, e.g., SAR, IR, video • breadboard of typical Adv. Fighter • information transfer between HITL systems (DEMPC and Adv. AWACS)

Figure 3-2: Interim and Final Demonstration Features

Task 6: Wireless ATM Study
The trade study of the on-board networks in the existing AWACS programs was performed. This trade study includes the off-board network; the survey and future works on wireless ATM technologies – wireless satellite, wireless terrestrial, and wireless mobile ATM.

4. ATM-BASED ARCHITECTURE DEFINITION (TASK 1)

Future airborne C^4I platforms, such as an Advanced AWACS, will increasingly have to provide sophisticated battle staffs with advanced command and control decision aids and multiple off-board/on-board sensor data fusion capability, resulting in the need for a real-time, higher data rate mission avionics network. This network must support multiple data types (data, voice, video, image) across multiple end-user stations on the aircraft, and eventually seamless communication capability between end-user stations on-board and off-board the aircraft.

4.1. ATM Technology for AWACS Platforms

Functional requirements of these C^4I aircraft will include interactive fighter control (voice), sensor data processing (including imagery) for targeting and situation assessment, real-time control of guided weapons, and Remotely Piloted Vehicles (RPV) with sensor payloads. Data rate requirements internal to the C^4I aircraft are expected to progress rapidly from 1 Mbps currently for the E-3, through approximately 5 to 10 Mbps for retrofits to current platforms (e.g., E-6), to 500 to 600 Mbps for future C^4I systems.

In an ATM network, the information is transported by means of streams of short fixed-length packets (cells) that are asynchronous time-division multiplexed. ATM is expected to be capable of effectively emulating any service and thus provide high-throughput, low-delay, service independent transport for all types of traffic. The advantages of ATM are:

- Flexibility to support existing services and unforeseen future services.
- Dynamic bandwidth allocation.
- Integrated transport of all types of mixed media information.
- Efficient use of network resources by statistical multiplexing.

Therefore, the architecture for future C^4I aircraft networks will take advantage of ATM technology to provide the network with the capacity for a wide variety of applications ranging from highly interactive to minimally interactive systems.

4.2. AWACS Open System Architecture Network Requirements

The AWACS Open System Architecture (OSA) requirements are as follows:

(a) Support periodic database distribution, on-demand messages, file sharing, video, and voice.
(b) Support very high multicast data load (> 40 Mbps) to each node for database distribution (up to 32 nodes).
(c) Support node scalability to 48 nodes.
(d) Support full capability of TCP and UDP (for multicast) on the network, although it does not have to be locked into using IP for database distribution.
(e) The buffer overflow should be avoided at end nodes. The end nodes which receive multicasts will be very susceptible to buffer overflow conditions and the host

processors cannot be dependent on the Network Interface Cards (NICs) buffer capacity at a line rate. Therefore, a flow control mechanism is required.

(f) No single-point failure modes.

(g) Each node needs to attach to two networks (dual homing).

(h) Database distribution does not necessarily need to be on top of an internetworking or routing protocol. No routing can take place for any data on the network. The set of data configurations on the network will not change frequently.

4.3. Demonstration Systems Architecture Definition

Analysis of tactical or reconnaissance Hardware-In-The-Loop (HITL) and C^4I applications using Advanced AWACS as the centralized airborne information platform leads to the conclusion that the corresponding system architecture is a critical aspect of the system's ultimate effectiveness in that role. The choice of communications architecture is constrained by the required functional architecture of the system, such as legacy interfaces, monitor and control stations.

Our rationale for migrating to ATM is based on expected benefits in network attributes from both theoretical and practical perspectives. Although some of the features of ATM are not currently available off the shelf, or currently require integration and rework to be operable, we are convinced that the long-term benefits will outweigh the short-term difficulties, hence the importance of this work.

The appropriateness of ATM versus a switched-LAN implementation is based on two important practical considerations. The first consideration centers on the ability to seamlessly support all forms of potential applications, i.e., multi-media, simultaneously and completely. In this regard, only ATM combines the advantages of statistical multiplexing with the use of small connection-oriented data cells to achieve practical jitter performance and optimal link utilization. Also, while most existing Application Programmable Interfaces (APIs) are compatible with any LAN technology, only ATM allows for eventual migration to native ATM APIs whereby many of the subtle advantages of ATM will be realized.

The second consideration centers on the relative ease with which network data can be converted and carried on different media such as LANs and telecommunications lines, optical fiber, and air. To date, ATM is by far the strongest long-term candidate for use as a communications substrate technology between these differing communication forms. Examples are LAN Emulation (LANE), ATM on T1, ATM on OC-3c, and link accelerators and modems necessary to implement an ATM RF air interface. Given the strong push for current and future remote operability and equipment interoperability, ATM appears to be the best long-term choice.

We defined three system architectures: the *existing* system configuration (Figure 4.3-1), the *interim* system configuration (Figure 4.3-2), and the *final* system configuration (Figure 4.3-2).

Existing Architecture: The existing system configuration of an integrated battlespace simulation (Figure 4.3.1) employs separate Ethernet and FDDI networks to implement message bursts and file transfers, respectively. The Ethernet connects the mission computer to the display consoles via the 10Base-2, tapped coaxial cable configuration. An additional Ethernet is used to provide connectivity to the Distributed Interactive Simulation (DIS) network. The FDDI connects not only the same workstations as the Ethernet, but also connects the Data Exploitation, Mission Planning, and Communications (DEMPC) mission planner and DEMPC image analyzer, providing the high-speed communications core of the system. The FDDI network employs an additional concentrator unit that serves to convert the physical topology of the network from a ring to a star.

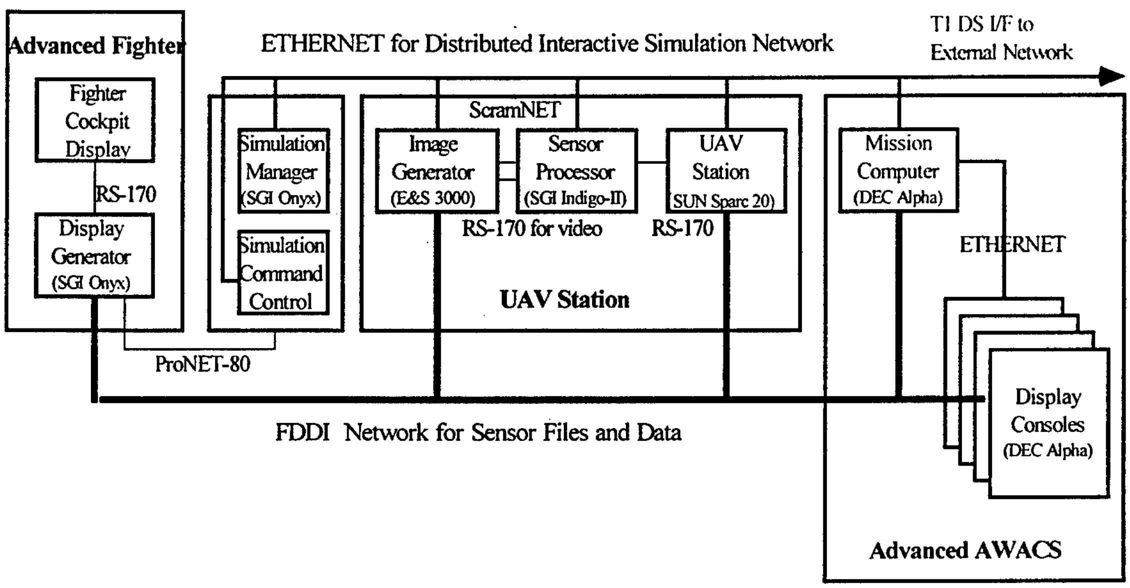


Figure 4.3-1: Existing Integrated Battlespace Simulation Demonstration System

Interim Demonstration Architecture: The interim system configuration (Figure 4.3-2) combines the data traffic present on the separate Ethernet and FDDI networks onto an ATM backbone. ATM LAN Emulation (LANE) technology will be used against separate Permanent Virtual Circuits (PVC) to establish connectivity similar to that in the existing system configuration. ATM LANE can support all existing IP applications, so TCP/IP and UDP/IP can run over LANE. The PVCs will also be able to support OSA database multicasts while a separate "Classical IP over ATM" (RFC 1577) will run simultaneously over Switched Virtual Circuits (SVC) supporting all existing IP applications. As such, the ATM backbone will provide connectivity between the OSA mission computers, the OSA display consoles, the DEMPC mission planner, and the DEMPC image analyzer, providing all inter-workstation communications for the system. The ATM backbone employs an ATM switch in the final system configuration.

Final Demonstration Architecture: The final system configuration (Figure 4.3-2) connects the UAV subsystem and advanced fighter subsystem to the Advanced AWACS subsystem. The UAV subsystem consists of the UAV sensor and ground station. The advanced fighter subsystem comprises the cockpit display and the display generator. For the actual demonstration, a simulated real-time Synthetic Aperture Radar (SAR) image will be used. The SAR image will be taken from the image generator's visual database. The video data will be captured and processed by the SGI Indigo2 sensor (SAR) video processor and transmitted via an RS-170 video link to the image analysis display on the DEMPC ground station. Additional information will be added to the image which will then be transmitted via ATM to the OSA DEC Alpha AWACS operator's station. The resultant image will then be passed to the SGI Onyx cockpit display processor via an ATM link along with voice communications between the shooter and the C^4I platform. The information that is displayed in the shooter's cockpit will be used as targeting information.

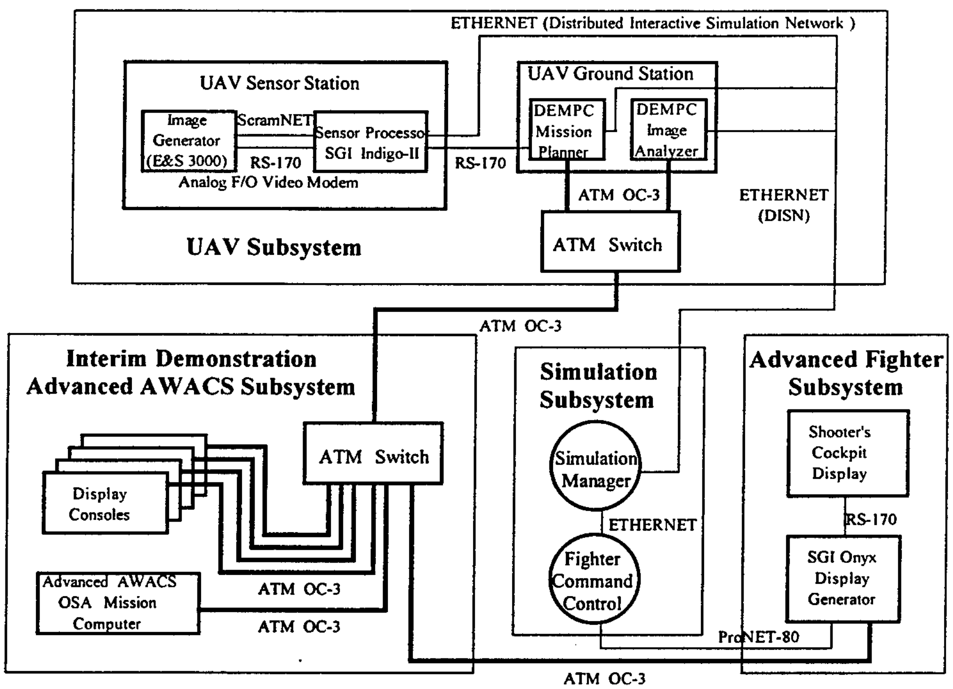


Figure 4.3-2: Interim and Final Demonstration System

4.4. ATM Multicast Solutions for AWACS Applications

The C^4I platform (e.g., AWACS) requires a network that is capable of simultaneous unicast and multicast for data distribution. The TCP/IP unicast is used for operator-related activities between the AWACS mission computer and display consoles. The UDP/IP multicast is used for common data broadcasting to all display consoles within a multicast group on a periodic basis. Unlike a connectionless legacy LAN technology, the multicast capability is not easy to implement with connection-oriented ATM technology. The ATM multicast configuration used for the integrated battlespace simulation network is described in the following sections.

4.4.1. ATM Multicast Technology

There are potential approaches to address the ATM multicast problem in the legacy LAN environment; for example, multipoint-to-multipoint Virtual Path Connections (VPC), a multicast server, or overlaid point-to-multipoint connections. However, the multipoint-to-multipoint VPC requires a protocol to allocate unique VCI values to all nodes in the multicast group; such a mechanism does not currently exist. The multicast server requires a point-to-multipoint connection with all nodes, as well as a point-to-point unidirectional connection from each node to a multicast server. The overlaid point-to-multipoint connections requires each node to maintain the total number of all connections within each group. Thus, there is no ideal solution yet for ATM multicast. The existing "Classical IP over ATM (CIP)" protocol supports neither broadcast nor multicast, while the ATM LAN Emulation (LANE) protocol supports only a broadcast. The higher layer protocols for ATM IP multicasting (e.g., MARS, MPOA, PIM) are under development.

4.4.2. ATM Classical IP-Based Multicast Solution

The ATM classical IP (CIP) protocol lacks a broadcast (multicast) mechanism. We resolved this broadcast (multicast) problem of ATM classical IP with a simple configuration solution. The simple solution is to set up point-to-multipoint Permanent Virtual Circuit (PVC) connections (Multicast_PVC) from a broadcast server to all clients. Since there is no such server in CIP, we create a virtual broadcasting node (that corresponds to a broadcast service access point) at the switch. The procedure to configure this CIP broadcast (multicast) mechanism is as follows.

(a) Configure an ATM interface (qaa0) for a standard "Classical IP over ATM" with an appropriate ATMARP server address, operating over Switched Virtual Circuit (SVC) connections.

(b) Create at an ATM switch a point-to-multipoint Permanent Virtual Circuits (PVC) node (Multicast_PVC) using unique vpi/vci numbers for each multicast group, e.g., AWACS, Fighter, and UAV multicast group subnets. This Multicast_PVC virtual node serves as a broadcasting access point.

(c) Create a virtual IP address for the Multicast_PVC virtual node. Note that a unique IP subnet address should be assigned to each multicast group when multiple subnets are required.

(d) Configure a new ATM interface (qaa1) for a CIP Multicast_PVC virtual node at both the host and the client workstations with a proper virtual IP address. Repeat the process for the multiple subnets, as required.

- ifconfig qaa1 <host station multicast IP address> netmask 255.255.255.0 at a host station.
- ifconfig qaa1 <client stations multicast_PVC virtual IP address> netmask 255.255.255.0 at all client stations.

(e) Bind IP addresses to the unique vpi/vci numbers at a host workstation and multiple client workstations, such as

- atmarp -c <client stations multicast_PVC virtual IP address> qaa1 <vpi> <vci> <revalidate> at a host station.
- atmarp -c <host station multicast IP address> qaa1 <vpi> <vci> <revalidate> at all client stations.

(f) Make the final configuration (e.g., atmarp) persistent across reboots by a start up script as necessary.

Run a standard "Classical IP over ATM" on top of "Multicast_PVC". This permits the simultaneous transmission of point-to-point TCP unicast traffic over SVC, and point-to-multipoint UDP multicast traffic over multicast_PVC.

4.4.3. ATM LAN Emulation-Based Multicast Solution

ATM LANE can support multiple independent emulated LANs (ELAN), and the membership in any of the ELANs is independent of the physical location of the end system. For the integrated battlespace simulation, four different ELANs were set up to support the ATM multicast groups: ELAN-1 (AWACS display consoles subnet), ELAN-2 (fighter subnet), ELAN-3 (UAV subnet), and ELAN-4 (voice over ATM subnet). The AWACS mission computer must be a member of all ELANs so that it can selectively broadcast information to any of the AWACS, fighter, or UAV groups as different multicast groups. It should be noted that the CIP (or LANE) intrasubnet protocol works only within its own logical IP subnet (or ELAN), thus a separate router is required for communications between different logical subnets (or ELANs).

Initialization and Configuration:

(a) LAN Emulation Client (LEC) registers its own ATM address.
- Upon initialization (power up), LEC obtains its own ATM address typically through address registration.

(b) LEC requests to join ELAN.
- LEC first finds the LAN Emulation Configuration Server (LECS) address by either the locally configured ATM address (bypassing LECS), Interim Local Management Interface (ILMI), well-known LECS address, or PVC (VPI=0, VCI=17).
- LEC sets up a bidirectional point-to-point connection *(Configure Direct VCC)* to LECS and sends LE_CONFIGURE_REQUEST to find LES ATM address.

(c) LECS identifies LAN Emulation Server (LES) and provides LES identification to LEC.
- LECS returns LE_CONFIGURE_RESPONSE to LEC with LES ATM address, ELAN type, ELAN name, and ELAN maximum packet size.

Joining and Registering with LES:

(d) LEC registers with LES
- LEC clears the configuration-direct connection to LECS and sets up a bidirectional point-to-point connection *(Control Direct VCC)* to LES for exchange of the control traffic and then sends LE_JOIN_REQUEST.
- When Control Direct VCC is established between LEC and LES, it remains so that no two LECs register the same Medium Access Control (MAC) or ATM address.

(e) LES verifies with LECS that LEC is allowed to join the ELAN
- Upon receipt of LE_JOIN_REQUEST, the LES sets up bidirectional point-to-point connection *(Server Configure Direct VCC)* to LECS for verifying that LEC is allowed to join the ELAN.
- LES configuration request *(Server Configure Direct VCC)* contains LEC MAC address, LEC ATM address, and ELAN name.
- LECS checks its database to determine whether the LEC can join the ELAN; then it uses the same VCC to inform the LES whether the LEC is allowed to join.

(f) LES allows or does not allow the LEC to join the ELAN.
- Upon verification of LEC's membership, LES adds the LEC as a leaf and sets up the unidirectional point-to-multipoint connection *(Control Distribute VCC)*.
- LES confirms the registration over bidirectional point-to-point connection *(Control Direct VCC)* by sending LE_JOIN_RESPONSE to the LEC. LEC has successfully joined the LES. On the other hand, if not allowed, LES rejects the registration over bidirectional point-to-point connection *(Control Direct VCC)*.

Finding and Joining the Broadcast and Unknown Server (BUS):

(g) LEC sends LE-ARP packets to LES for finding the BUS ATM address.
- LEC creates a LE_ARP_REQUEST packet with MAC address (0xFFFFFFFF) and sends it to LES over the control-direct VCC to find a MAC broadcast address.
- LES responds to LEC with the BUS ATM address on the control-distribute VCC.

(h) LEC sets up the multicast-send connection to BUS.
- LEC creates a signaling packet with BUS ATM address and sets up a bidirectional point-to-point connection *(Multicast Send VCC)* to BUS.

(i) BUS sets up the multicast-forward connection to LEC.
- Upon receipt of a signaling packet, BUS adds the LEC as a leaf and sets up an unidirectional point-to-multipoint connection *(Multicast Forward VCC)* to LEC. (Note that the BUS is allowed to set up the unidirectional point-to-point VCCs to LECs, but the use of point-to-multipoint VCCs relieves the BUS from duplicating and transmitting many copies of each message).
- LEC is now a member of the ELAN and is ready for data transfer.

Data Transfer:

(j) BUS floods a data packet to all LECs on the ELAN.
- When LEC has a data packet to send to an unknown destination MAC address, LEC sends the data frame to BUS over the multicast-send VCC and the BUS distributes it to all LECs on the ELAN over the multicast-forward VCC.
- This is done because the ATM address resolution may take some time and many network protocols are intolerant of delays.

(k) LEC resolves an ATM address of the unknown destination LEC.
- LEC sends a LE_ARP_REQUEST control frame to LES over the control-direct VCC. If LES knows the answer, it will respond with the ATM address corresponding to the Medium Access Control (MAC) address of the LEC.
- If LES does not know the answer, it floods the LE_ARP_REQUEST to some or all LECs over the control-distribute VCC.

(l) LEC sends BUS LANE flushing message and then starts data transfer
- Upon receipt of LE_ARP_RESPONSE, LEC sets up a bidirectional point-to-point connection *(Data Direct VCC)* to the destination LEC and uses this for data transfer rather than the BUS path.
- When LEC establishes the data-direct VCC, it sends a control broadcast message (i.e., *FLUSH MESSAGE*) following the last packet to BUS and waits for the destination to acknowledge receipt of the flush packet. The LANE Flush procedure ensures that all packets previously sent to the BUS were delivered (flushed) to the destination prior to the use of the data-direct VCC.
- The LEC then starts to send data across the data-direct VCC without the risk of frames interleaving.

5. ATM NETWORK IMPLEMENTATION (TASK 2)

The primary objective of this task was to integrate all components of the Advanced AWACS subsystem into the final demonstration configuration. In this task, first we performed a vendor trade study on the necessary COTS hardware and software, second we acquired all required system components, and finally we integrated all components of the Advanced AWACS subsystem into the interim demonstration configuration.

5.1. ATM Switch and Analyzer Selection

The trade study on the selection of COTS hardware (e.g., ATM switch), software, and related test equipment was performed. After an initial screening, three vendors' products were selected as candidates.

ATM Switch Requirements: The ATM switch had to address the full range of requirements including:

- Broadcast/multicast capability.
- LANE BUS throughput (> 40 Mbps) to each node (up to 32 nodes).
- Support full TCP/IP and UDP/IP capability on the network.
- No buffer overflow at end nodes.

Evaluation: A list of our requirements was provided to the vendors. Based on these requirements, a series of technical evaluations and tests on the preselected vendors' ATM switches were performed during this reporting period. The major issues were the multicast capability and LAN Emulation (LANE) Broadcast and Unknown Server (BUS) throughput, which are the important metrics for real-time C^4I systems. The ATM LANE BUS is responsible for forwarding all broadcast (or multicast) and unknown destination unicast frames (received from members of the ELAN) to all members of the ELAN. The LANE BUS throughput test measures the ability of a BUS to forward frames. Since the AAL5 Protocol Data Units (PDU) do not allow the interleaving of cells of different frames during the forwarding procedure, the BUS should serialize the received frames prior to forwarding them. As a result, the performance of the Segmentation And Reassembly (SAR) on the BUS is the most significant factor affecting overall BUS performance. Given the fact that some BUS implementations perform the SAR in software, while others provide it in hardware, the BUS performance varies substantially. The following Figure 5.1-1 summarizes the evaluation and test results on the major vendors' ATM switches.

Conclusion: Based on the trade study and a series of evaluation and testing efforts, we selected the Cisco Systems LS-1010 ATM switch (with Catalyst 5000 LANE module) and the 3Com Cellplex 7000 ATM switch.

Requirements or Capabilities	CISCO LS1010 with Catalyst 5000	FORE ASX-200BX	3COM CellPlex 7000
1. Switch call setup rate (450 calls)	195 calls completed per second	130 calls completed per second	11 calls completed per second (limit to 325 calls)
2. Switch call setup latency (450 calls)	< 0.1 sec	> 2.0 sec	-
3. ATM LANE	Yes	Yes	Yes
4. BUS/LES location	Outside switch, in a different box (Catalyst 5000)	Inside switch, in the same box	Outside switch in the same box
5. SAR implement on the BUS	SAR in hardware	SAR in software (This limits BUS performance)	SAR in hardware
6. LANE multicast capability	Yes	Yes	Yes
7. Throughput (50 Mbps to 32 clients)	Yes	No	Yes
8. BUS broadcasting speed	14,881 frames/sec over 1 ELAN 119,000 frames/sec over 6 ELANs	1,488 frames/sec over 1 ELAN	14,881 frames/sec over 1 ELAN 89,000 frames/sec over 6 ELANs
9. BUS throughput	4,880 frames/sec for 24-frame burst 5,480 frames/sec for 744-frame burst	2,060 frames/sec for 24-frame burst 2,060 frames/sec for 744-frame burst	4,880 frames/sec for 24-frame burst 7,440 frames/sec for 744-frame burst
10. Frame handling (% successful deliver)	100 %, 94 % for 24-, 744-frame bursts	32 %, 27 % for 24-, 744-frame bursts	100 %, 100 % for 24-, 744-frame bursts

Figure 5.1-1: Performance Comparison of Multiple Vendors' ATM Switches

<u>ATM Network Analyzer Requirements:</u> The ATM network analyzer should be able to address the range of requirements, including:

- The ATM analyzer should be able to address all our requirements to satisfy the ATM network performance evaluation task during the program.
- The second ATM analyzer was required to be portable because of the need to move among three laboratories (Bldg. 7-81-7, Bldg. 18-233, or ITDL facility) due to multi-organizational involvement in this Rome Lab program for an ATM-based AWACS network demonstration.
- It was very highly desirable for the second ATM Analyzer to be compatible and/or interchangeable with the existing HP VXI-based E4100B ATM Broadband System.
- The ATM analyzer had to have an easy upgrade path to future higher data rates.

Evaluation: The list of test standards and parameters were provided in advance to the vendors. Based on the given test standards and parameters, a series of evaluation and testing on the selected major vendors' ATM analyzers were performed in our laboratory during this reporting period. Figure 5.1-2 summarizes the ATM analyzer evaluation and test results.

Capability	HP 4100B	HP 5200A	W&G DA-30C	Note
1. Decoding capability of traffic in monitoring mode	Yes	Yes	Yes	At various protocol layers such as ATM, AAL, LANE, TCP, UDP, Classical IP
2. Capture capability of traffic	Yes	Yes	Yes	As an edge device over UNI under LANE, Classical IP, AAL, and ATM
3. Source capability of traffic	Yes	Yes except LANE	No Yes with PVC except LANE	As an edge device over UNI under LANE, Classical IP, AAL, and ATM
4. Emulation capability	Yes	Yes for UNI, NNI	No No NNI (Some emulation available in Version 2.0)	Traffic capture and analysis UNI signaling in emulation NNI signaling in emulation
5. Conformance test	Yes	No	No	UNI, NNI signaling
6. Quality of Service (QoS) test capability	Yes	Yes	No for some QoS parameters (Improve in Version 2.0)	Cell delay variation (jitter) Maximum cell delay Mean cell delay Cell loss, cell error ratio Cell misinsertion ratio, etc.

Figure 5.1-2: Performance Comparison of Multiple Vendors' ATM Analyzers

Conclusion: Based on the trade study and a series of evaluation and testing efforts, we selected a Hewlett-Packard E5200A portable broadband service analyzer that was superior to any other models. Without the version 2.0, the capability of the existing version 1.2 of the Wandel & Golterman (W&G) DA-30C ATM analyzer, was somewhat limited.

5.2. AWACS-UAV-Fighter Platforms Selection

There were three different applicable platforms or environments: Digital Equipment Corporation (DEC) Alpha 600 processors running DEC Unix on a PCI backplane, SUN Sparc-20 workstations running Solaris on an Sbus backplane. and SGI Onyx workstations running IRIX on a VMEbus backplane. The first two systems were required for the interim demonstration and all three of them were required for the final demonstration. The core battlespace components were simulated with the multiple, high-end platforms on ATM network testbed (Figure 5.2): AWACS for DEC Alpha-500/600 workstations running Unix 4.0 on PCIbus, UAV for SUN Sparc-20 running Solaris 2.4 on Sbus, and Fighter for SGI Onyx-1 (Onyx-2) running Irix 5.3 (Irix 6.4) on VMEbus (PCIbus).

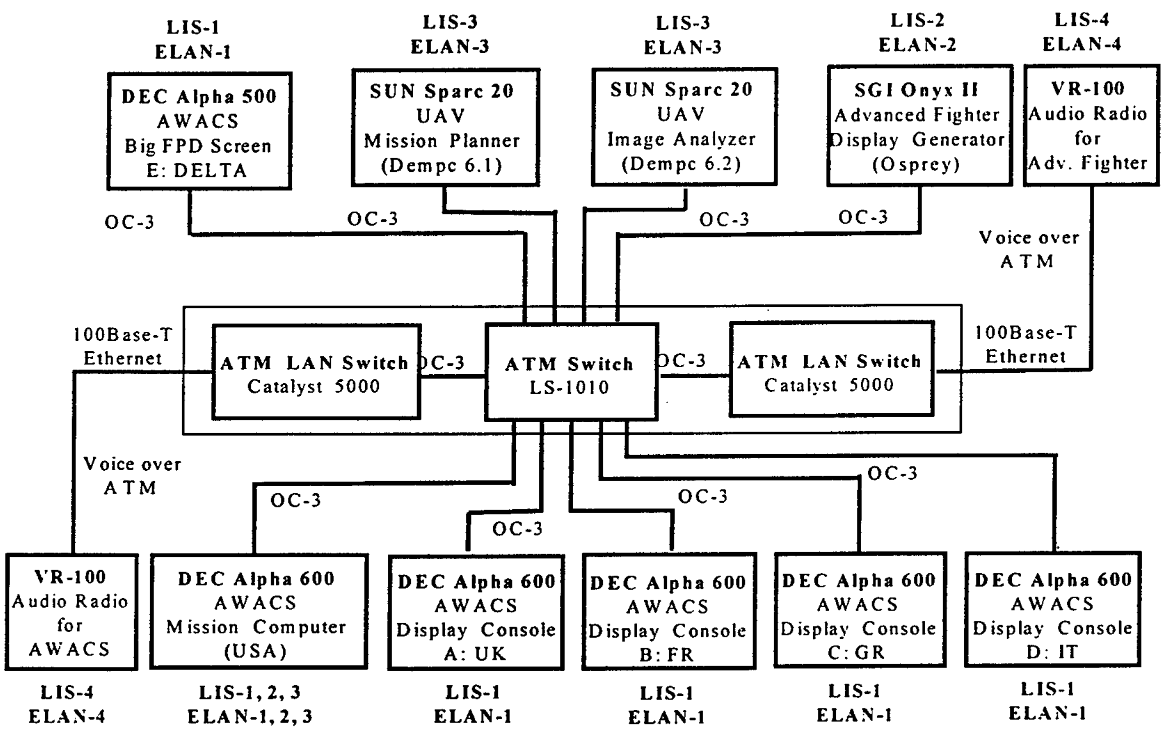


Figure 5.2: ATM Testbed for Integrated Battlespace Simulation

5.3. ATM Network Interface Cards Selection

The following ATM adapters were selected for each workstation platform of the battlespace components:

- FORE Systems PCA-200EUX ATM adapter for PCI-bus DEC Alpha-600 workstation.
- FORE Systems SBA-200E ATM adapter for S-bus SUN Sparc-20 workstation.
- FORE Systems VME-200 ATM adapter for VME-bus SGI Onyx-1 workstation.

The ATM adapter provides ATM connectivity for host systems and provides the following capabilities:

- Supports signaling and AAL standards.
- Supports for SVCs (through UNI 3.0/3.1 signaling) and PVCs.
- Provides ATM Classical IP, LAN emulation, and SNMP.
- Provides transparent support for TCP/IP.
- Provides ATM Applications Programmer Interface (API).

5.4. ATM Network Implementation

Figure 5.4 shows the workstation architecture (corresponding to the final demonstration architecture shown in Figure 4.3-2) which emphasizes the hardware and software components related to ATM connectivity. Each workstation has a processor, a backplane communications bus, an ATM adapter, device driver, protocol, and interface software, and an operating system. In addition, it is planned for the OSA mission computer to host the ATM network management software. The OSA software of the existing Advanced AWACS simulation system is hosted on DEC Alpha-600 workstations. One Alpha acts as the OSA mission computer. The other four Alphas act as the OSA display consoles.

The Data Exploitation, Mission Planning, and Communications (DEMPC) software of the existing Advanced AWACS OSA simulation system is hosted on two SUN Sparc-20 workstations. One SUN acts as the DEMPC mission planner and the other acts as the DEMPC image analyzer. The image analyzer and mission planner SUN Sparc-20 workstations have S-Bus slots available for the ATM adapter.

The shooter display generator software is hosted on one Silicon Graphics Onyx-1 or -2 workstation. This Onyx has one 9U VME slot available and a VME adapter is used for the baseline ATM interface. It is important to note that the portion of this demonstration that specifically relates to on-board the C^4I platform itself (i.e., OSA mission computer, display console, and the DEMPC analyzer) closely approximates a real-life scenario.

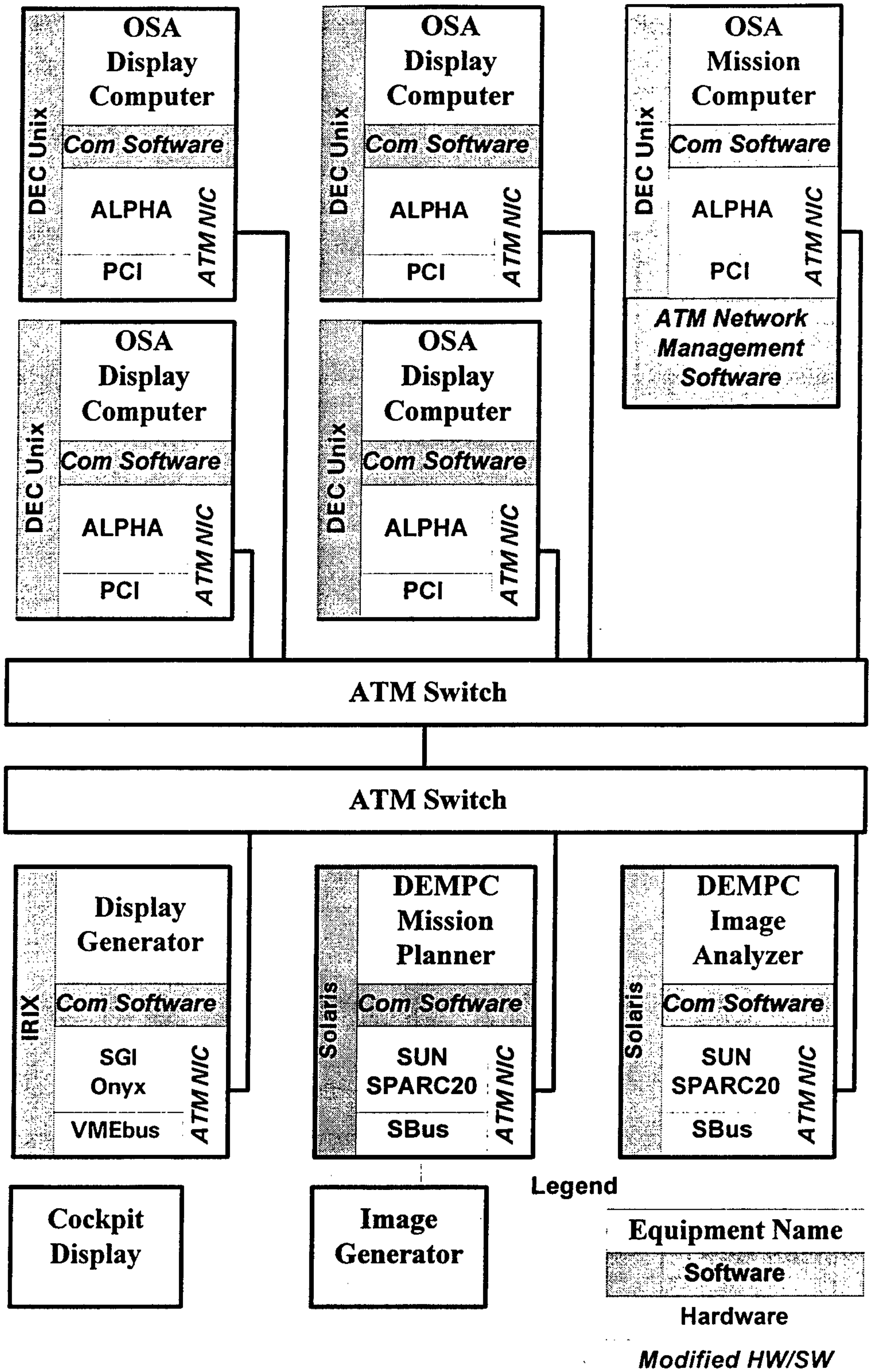


Figure 5.4: Workstation Architecture Components

5.4.1. Parts List for ATM Implementation

The equipments and components required for the demonstration systems include two ATM switches with multiple OC-3 and DS-3 ports, an ATM LANE module, eight ATM network interface cards on three different platforms, various optical fibers and cables. The parts list and workstations list are shown in Figure 5.4.1-1 through Figure 5.4.1-3.

Item	Part Description	Part Number	Source	Qty
1	ATM switch with 2 modules of 8 ports OC-3; PNNI/IISP feature; ATM Director; H/W, S/W upgrade and maintenance	Lightstream LS-1010	Cisco Systems (206) 688-2204	1
2	ATM switch LANE module with H/W and S/W upgrade and maintenance support	Catalyst 5000	Cisco Systems (206) 688-2204	1
3	ATM switch with 2 modules of 8 ports OC-3; 1 module of 2 DS-3 ports; PNNI/IISP and LANE; ATM Manager; H/W, S/W upgrade and maintenance	Cellplex 7000	3Com Corp. (206) 450-4916	1
4	ATMworks 350 PCIbus ATM adaptor with OC-3C with LANE (UNIX 4.0)	DGLPB-AB	Digital Equipment Corp (206) 637-4263	5
5	PCIbus ATM adaptor with with LANE (UNIX 4.0)	PCA-200EUX/OC3SC	Fore Systems (206) 655-6433	1
6	Sbus ATM adaptor with OC-3C/SC connectors and SunOS & Solaris driver	SBA-200E/OC3SC	Fore Systems (206) 655-6433	2
7	VMEbus 6U ATM adaptor with OC-3C/SC connectors	VME-200/OC3SC-9U	Fore Systems (206) 655-6433	1
8	SC to SC, 62.5/125 μm multimode fiber, 150 ft	FOA6SC/6SC-62.5-PVC-150 ft	Connect Air (206) 813-5599	7
9	SMA to SC, 100/140 μm multimode fiber, 50 ft	FOA2SC/SMA-100-PVC-50 ft	Connect Air (206) 813-5599	2
10	DB-50P to DB-50P SCSI cable, 6 ft	654-1035-06	Connect Air (206) 813-5599	2

Figure 5.4.1-1: Parts List for ATM Network Implementation

Property and Serial No.	Description	Model PB560-A9	Media	Memory
39011518 NT720034II	Hammer: OSA mission computer	DEC AlphaStation 500 5/400	4.3 GB disk (qty 2) 3.5" floppy drive 4 mm DAT tape drive	128 MB Volatile
39011525 NT720034MQ	Ryobi: OSA display console	DEC AlphaStation 500 5/400	4.3 GB disk 3.5" floppy drive 135 MB Syquest drive	128 MB Volatile
39011526 NT720034KO	Delta: OSA display console	DEC AlphaStation 500 5/400	4.3 GB disk 3.5" floppy drive 135 MB Syquest drive	128 MB Volatile
39011517 NT720034GE	Punch: OSA display console	DEC AlphaStation 500 5/400	4.3 GB disk 3.5" floppy drive 135 MB Syquest drive	128 MB Volatile
39011527 NT720034KM	Bandsaw: OSA display console	DEC AlphaStation 500 5/400	4.3 GB disk 3.5" floppy drive 135 MB Syquest drive	128 MB Volatile
39011519 NT720034HG	Torx: OSA display console	DEC AlphaStation 500 5/400	4.3 GB disk 3.5" floppy drive 135 MB Syquest drive	128 MB Volatile
39011528 NT720034JK	Jigsaw: OSA display console	DEC AlphaStation 500 5/400	4.3 GB disk 3.5" floppy drive 135 MB Syquest drive	128 MB Volatile

Figure 5.4.1-2: List of DEC Alpha-500 Workstations

Property and Serial No.	**Description**	**Model** PB620-A9	**Media**	**Memory**
39010476 NI546008V6	USA: OSA mission computer	DEC Alpha 600 5/266		
39010478 NI546008U4	UK: OSA display console	DEC Alpha 600 5/266		
39010144 NI546008W8	France: OSA display console	DEC Alpha 600 5/266		
39010145 NI546008XA	Germany: OSA display console	DEC Alpha 600 5/266		
39010146 NI546008T2	Italy: OSA display console	DEC Alpha 600 5/266		

Figure 5.4.1-3: List of DEC Alpha-600 Workstations

5.4.2. ATM Adapter Installation Procedure

The installation procedure of the FORE ATM Network Interface Card for Digital Unix 4.0a ForeThought 4.0.3(1.3) PCA-200E Driver is described in this section.

FORE ATM Adapter Installation Procedure:

Release Notes: ForeThought 4.0.3(1.3) contains support for the tcpdump utility.

Be sure to log in as root.

Set the EDITOR environment variable to point to your favorite editor.

For example:

```
# EDITOR=/usr/dt/bin/dtpad
# export editor
```

If there is a previous version of the FORE driver installed, remove it from the kernal configuration using setld.

```
# setld -d <Build_Name>
```

If unsure what to put into <Build_Name>, use the output of:

```
# setld -i | grep FORE | grep installed | awk '{print $1}'
```

Now install the driver.

```
# mkdir /usr/tmp/fore
# cd /usr/tmp/fore
# ftp ftp.fore.com
login: ftp
password: <Your email address>
ftp> bin
ftp> cd /priv/release/sunny
ftp> get du_4.0.2_1.19.tar.Z
ftp> bye
# uncompress du_4.0.2_1.19.tar.Z
# tar xvf <filename>.tar
# cd ..                    /* Change directory to /usr/tmp/ */
# setld -l fore
```

/* Installation screen capture begins here. */

*** Enter subset selections ***
The following subsets are mandatory and will be installed automatically
unless you choose to exit without installing any subsets:

* FORE Systems, Inc PCA-200E

You may choose one of the following options:

1) ALL of the above
2) CANCEL selections and redisplay menus
3) EXIT without installing any subsets

Enter your choices or press RETURN to redisplay menus.

Choices (for example, 1 2 4-6): 1   /* Choose #1 */

You are installing the following mandatory subsets:

FORE Systems, Inc PCA-200E

You are installing the following optional subsets:

Is this correct? (y/n): y   /* Answer yes */

1 subset(s) will be installed.

Loading 1 of 1 subset(s)....

FORE Systems, Inc PCA-200E
Copying from fore (disk)
Verifying

1 of 1 subset(s) installed successfully.

Linking /usr/opt/AFTBASE402/fore to /usr/fore

Configuring "FORE Systems, Inc PCA-200E" (AFTBASE402)

FORE ATM Adapter Configuration Procedure:

Would you like to use FORE's SNMP agent? [y]
Would you like to use the standard UDP ports for SNMP(160/161)? [y]
Will ILMI be used for Address Registration? [y]
Would you like to configure Classical IP? [n]
Would you like to configure qaa0? [y]
Enter the ATM address for the ARP server
47.01.00.00.00.00.00.00.00.00.00.00.00.e0.14.24.7f.01.00
Would you like to configure qaa1? [y] n
Would you like to configure qaa2? [y] n
Would you like to configure qaa3? [y] n
Would you like to configure LAN Emulation? [n]

Next, build a new kernal using doconfig...

doconfig.

You will be prompted for a kernel config filename. For example, "FORE_ATM"

Choose at least KDEBUG and CDFS from the kernal option list. When it asks you if you want to edit the configuration file, answer y.
*** KERNEL CONFIGURATION AND BUILD PROCEDURE ***

Enter a name for the kernel configuration file. [TAC-ALPHA1]: FORE_ATM

A configuration file with the name 'FORE_ATM' already exists.
Do you want to replace it? (y/n) [n]: y

Saving /sys/conf/FORE_ATM as /sys/conf/FORE_ATM.bck

```
*** KERNEL OPTION SELECTION ***

Selection   Kernel Option
--------------------------------------------------------------
1      LAN Emulation over ATM (LANE)
2      Classical IP over ATM (ATMIP)
3      ATM UNI 3.0/3.1 Signalling for SVCs
4      Asynchronous Transfer Mode (ATM)
5      Advanced File System (ADVFS)
6      System V Devices
7      Logical Volume Manager (LVM)
8      Kernel Breakpoint Debugger (KDEBUG)
9      NTP V3 Kernel Phase Lock Loop (NTP_TIME)
10     Packetfilter driver (PACKETFILTER)
11     Point-to-Point Protocol (PPP)
12     STREAMS pckt module (PCKT)
13     X/Open Transport Interface (XTISO, TIMOD, TIRDWR)
14     File on File File System (FFM)
15     ISO 9660 Compact Disc File System (CDFS)
16     Audit Subsystem
17     ACL Subsystem
18     Logical Storage Manager (LSM)
19     All of the above
20     None of the above
21     Help
22     Display all options again
--------------------------------------------------------------

Enter the selection number for each kernel option you want.
For example, 1 3 [20]: 8 15  /* KDBUG and CDFS are 8 and 15 in this case */

You selected the following kernel options:

Kernel Breakpoint Debugger (KDEBUG)
ISO 9660 Compact Disc File System (CDFS)

Is that correct? (y/n) [y]: y

Do you want to edit the configuration file? (y/n) [n]: y

Using dtpad to edit the configuration file. Press return when ready,
or type 'quit' to skip the editing session:
```

At this point, you will be dropped into the editor defined by the $EDITOR environment variable.

Before the first 'options' line, add the following line:

options AFT403 ???

save and exit from the editor...
The kernel build will then proceed.

*** PERFORMING KERNEL BUILD ***

A log file listing special device files is located in /dev/MAKEDEV.log
Working....Thu Sep 26 15:21:29 EDT 1996
Working....Thu Sep 26 15:23:31 EDT 1996

The new kernel is /sys/FORE_ATM/vmunix
#

When it's done,

mv /vmunix /vmunix.pre_FORE /* optionally save the orginal kernel */
cp /sys/FORE_ATM/vmunix /vmunix

reboot

During bootup, you should see messages to the effect of:

fa0: FORE ATM pca-200e
...
Configuring FORE ATM
fa: waiting for firmware download...
fa: firmware download complete
fa0: 200-series operational

These messages indicate that the PCA-200E was recognized and the firmware was successfully downloaded.

(This completes the driver installation process.)

Once rebooted. login as root and configure the interface.

For FORE IP enter a command similar to:
ifconfig fa0 169.144.160.68 netmask 255.255.255.0 up

For Classical IP, enter a command similar to:
ifconfig qaa0 169.144.168.68 netmask 255.255.255.0 up

For LAN Emulation:
/usr/fore/etc/configure_lanem /* See the User's Manual for instructions */
ifconfig el0 up

In order to permantly preserve IP configuration during reboots, run /usr/sbin/netsetup as described in chapter 4 of the Digital Unix PCA-200E User's Manual.

<u>Summary</u>:

- Install the NIC

- Install the software subset:

  setld -l /apps/Special/fore AFTBASE402

- Configure FORE ATM Adapter

  Would you like to use FORE's SNMP agent? [y] y
  Would you like to use the standard UDP ports for SNMP(160/161)? [y] y
  Will ILMI be used for Address Registration? [y] y
  Would you like to configure Classical IP? [n] y
  Would you like to configure qaa0? [y] y
  Enter the ATM address for the ARP server
  47.01.00.00.00.00.00.00.00.00.00.00.00.e0.14.24.7f.01.00
  Would you like to configure qaa1? [y] n
  Would you like to configure qaa2? [y] n
  Would you like to configure qaa3? [y] n
  Would you like to configure LAN Emulation? [n] y

- Rebuild the kernel:
  setenv EDITOR vi
  setenv VISUAL vi
  doconfig

- When it asks if you want to edit the config file, answer yes and add the following options line:

  options AFTBASE402

- Install the new kernel and reboot.

Note: At this point, the Fore commands are in /usr/fore/etc/

- Run netsetup and configure qaa0.
- Alternative method, assuming system previously had exactly 1 interface:

```
echo "137.136.33.35 belugafd atmipaddr" >> /etc/hosts
echo "137.136.33.250 atmswitch" >> /etc/hosts
echo "137.136.33.251 mcast-dest-IP-addr" >> /etc/hosts
rcmgr set NUM_NETCONFIG 2
rcmgr set NETDEV_1 "qaa0"
rcmgr set IFCONFIG_1 "atmipaddr netmask 255.255.255.0"
```

- Associate a PVC for qaa0:

Note that this will need to be added to a startup script.

```
/usr/fore/etc/atmarp -c mcast-dest-IP-addr qaa0 0 255 0
```

- Enable IP aliasing:

(****** This will need to be added to a startup script *******)

```
ifconfig qaa0 alias mcast-dest-IP-addr netmask 255.255.255.0
```

- Test qaa0:

```
ping atmipaddr
ping atmswitch
ping [something else]
/usr/fore/etc/atmarp -a
```

- Configure LANE:

(Note: The first two lines are in lieu of running the configure_lanem script.)

```
echo "LECS_NSAP_ADDR=-wellknown; export LECS_NSAP_ADDR" > /usr/fore/etc/fore_lanem.conf
echo "DEFAULT_ELAN="default"; export DEFAULT_ELAN" >> /usr/fore/etc/fore_lanem.conf
echo "137.136.41.35 belugaelan" >> /etc/hosts
rcmgr set NUM_NETCONFIG 3
rcmgr set NETDEV_2 "el0"
rcmgr set IFCONFIG_1 "belugaelan netmask 255.255.255.0"
```

• Test el0:

/usr/fore/etc/elconfig show -all
ping belugaelan
ping [something else]

Notes:
- If the switch changes, you'll need to enter a new NSAP address into /usr/fore/etc/fore_atm.config for RFC1577 to work.

- The subset install process sets up /sbin/init.d/foreatm, which configures things based on /usr/fore/etc/fore_atm.config and /usr/fore/etc/fore_lanem.conf.

5.4.3. ATM Adapter Installation Problems

DEC Alpha 500 workstations were not compatible with FORE Systems' PCI-bus ATM adapters (ForeRunner PCA-200E), resulting in serious ATM integration problems. Several of the problems that were encountered are summarized here.

Workstation 1 (Hostname: Punch): Among the five Alpha 500 workstations delivered to the ITDL, one station (hostname: Punch) was assembled with an old circuit board and old Firmware (version 3.8) while the rest were assembled with new circuit boards and new Firmware (version 3.9). When FORE's ATM adapters were installed into all five stations, the Punch station came up with no apparent problems, but the rest of the stations didn't come up at all.

Workstation 2 (Hostname: Torx): This station didn't come up initially. After running a series of status commands, the FORE's ATM adapter suddenly started working. After rebooting the workstation, it still came up just fine. At this time no clear explanation can be provided why it started working.

Workstation 3 (Hostname: Ryobi): This station didn't come up at all. The problem was that the Firmware v.3.9 was not downloaded to the ATM card. After getting the Firmware downloaded manually, it was discovered that the FORE's SNMP daemon (snmpd) was not running. Apparently, the FORE ATM adapter kills DEC's SNMP daemon and reloads its own snmpd, but it does not run the snmpd. After starting the snmpd manually, we still cannot join the ATM ELAN. This problem was resolved by removing the existing ELAN, reconfiguring the temporary "default ELAN," and reinitializing the interface with the IFCONFIG command. This station (Ryobi) successfully joined the ELAN and the ATM LAN emulation was operational.

Workstation 4 (Hostname: Hammer): The same procedure used in the workstation 3 was tried to fix the Hammer station. It came back with an error message of having a duplicate MAC address, so it would not allow it to join the ELAN. Apparently, we needed to set up a temporary "default ELAN." With this default ELAN set up, the ATM card was enabled to come up and successfully joined the ELAN.

Workstation 5 (Hostname: Bandsaw): The same procedure used in workstation 4 fixed the Bandsaw station.

After getting all stations up manually, another problem arose; the system would not come up to the users accounts. After trouble-shooting, it was found that when we brought the system up manually, the system lost the fix that enabled the card to come up at system initialization. This was done by hacking FORE's startup scripts. However, this fix was only temporary and each individual workstation could not be made consistently operational; it only worked randomly.

Punch DEC 500 workstation has the following software version:

SRM Console: V6.3-11
ARC: 4.49
Palcode: VMS palcode V1.18-0, OSF Palcode V1.21-0
SROM Version: V2.05
Motherboard has 21164-1 DEC ALPHA CHIP

This system recognizes the FORE Systems ATM card and loads firmware correctly.

All other remaining DEC 500s have the following software versions:

SRM Console: V6.4-5 Feb 21, 1997
ARC: 4.52
Palcode: VMS palcode V1.18-0, OSF Palcode V1.21-0
SROM Version: V2.05
Motherboards have 21164-2 DEC ALPHA CHIP

These systems do not work with FORE Systems ATM cards.

5.4.4. ATM Adapter Installation Problems Fix

All hardware for the five new Digital Equipment Corporation (DEC) Alpha-500 workstations was assembled in the unclassified area of the D-1 Lab, while the existing DEC Alpha-600 workstations were already set up in the classified area of the D-1 Lab of the ITDL. The FORE Systems' ATM Network Interface Cards (NIC) were installed into the new DEC Alpha-500 workstation. However, the ATM NICs were not properly functional due to the driver software incompatibility with a new DEC Alpha-500 workstation. It was found that the FORE Systems' ATM NICs (PCA-200 ATM PCI-bus adapter for DEC Alpha) did not support a newer model of DEC Alpha-500 workstation. The approaches we undertook to address the problems were as follows:

a) First, we tried to debug the problems associated with FORE's ATM NICs on DEC Alpha-500 workstations. This debugging effort was partially successful and we could make each workstation operational (as described in section 5.4.3) but only in a certain timing condition. It was not consistently working and required frequent rebooting. The rebooting procedure was not normal and was very complicated. In addition, FORE Systems would not support ATM NICs for the DEC Alpha-500 workstation.
b) Second, we tried DEC's own ATM NICs (ATMWork 350 adapter) on the DEC Alpha-500 stations and they did not work, either. The ATM NICs for a newer model of the Alpha-500 workstation were not yet available even within DEC.
c) Third, we tried the FORE's ATM NICs on DEC Alpha-600 workstations and verified that FORE's ATM NICs were functional with DEC Alpha-600 workstations.

d) Fourth, we verified that the FDDI NICs were compatible with new DEC Alpha 500 workstations. One of the AWACS systems in the classified area would remain in the FDDI configuration for a while.

Following a month-long debug procedure, we decided to exchange the new DEC Alpha-500 workstations in the unclassified area with the existing DEC Alpha-600 workstations of the AWACS demonstration system in the classified area. Since DEC Alpha-600 workstations were functional with FORE ATM NICs while DEC Alpha-500 workstations were operational with FDDI NICs, we swapped DEC Alpha-500 with Alpha-600 for the proper operation of both systems. After the workstation exchange, the ATM network was immediately functional with the same FORE's ATM NICs that allowed us to start the benchmarking test. Besides, the FDDI network was also functional with DEC Alpha-500 workstations in the classified area of D-1 Lab, which allows for ITDL's day-by-day Advanced AWACS demonstration.

05/29/97:	DEC Alpha 500 workstations received.
06/03/97:	DEC engineer installed DEC Alpha 500s.
06/05/97:	Discovered a problem of DEC Alpha 500s with FORE's ATM adapter.
06/06/97:	DEC engineer completed repairs to a DEC Alpha 500 - PUNCH workstation replaced the motherboard.
06/10/97:	Determined DEC Alpha 500's incompatibility with FORE's ATM adapter. Note: Punch workstation's motherboard replaced due to a SCSI problem.
06/19/97:	Decided to swap DEC Alpha 500s with DEC Alpha 600s.
06/20/97:	FORE's ATM adapter worked well with DEC Alpha 600 workstations. Problem with DEC Alpha 500s did not occur with DEC Alpha 600s.
06/23/97:	Requested FORE Systems to resolve the problem on the DEC Alpha 500s. Asked if FORE's ATM adapter would support DEC Alpha 500s and also asked about any known problems if the adapter would not support the DEC Alpha 500s. FORE Systems was not aware of any issues.
06/30/97:	Received a response from FORE Systems. Fore Systems became aware of the problem. FORE Systems neither supports DEC Alpha 500s nor has any future plans to support it.

Note: This incompatibility issue was revisited later during the final system integration. However, at the time of final demonstration, the proper ATM adapters were still not available for DEC Alpha-500 workstation. Therefore, the FDDI network with DEC Alpha-500 workstations could not be migrated to ATM. The one option is to use LAN Emulation (LANE) through FDDI LAN switch since the latest LANE technology supports FDDI.

6. SYSTEM TEST AND PERFORMANCE EVALUATION (TASK 3)

One of the important objectives of this program was to evaluate the performance of an Asynchronous Transfer Mode (ATM) backbone network designed to replace the existing FDDI/Ethernet networks for the Advanced AWACS mission avionics systems. The test plan addressed ATM switch test, switch interoperability test, multicast configuration test, and performance evaluation test of ATM-based Advanced AWACS interim demonstration subsystems. The subsystem evaluation test had two components: One was an ATM network performance test such as throughput, latency, and cell loss; the other was an application performance test using an AWACS application program.

The AWACS mission computer uses client/server displays. These client/server displays were demonstrated to ensure that ATM would handle the client/server messaging protocol in a manner that is required for a real-time command and control system. The transmission of real time messages and the network performance were investigated. The Ping and Bing (Bandwidth Ping) were used for verification of network connection and the Netperf (Network Performance Benchmark) and/or NTTCP (Network Trivial Transmission Control Protocol) software tools were used to investigate the traffic loading impact on ATM network performance. The AWACS network performance measure was focused on the maximum achievable throughput.

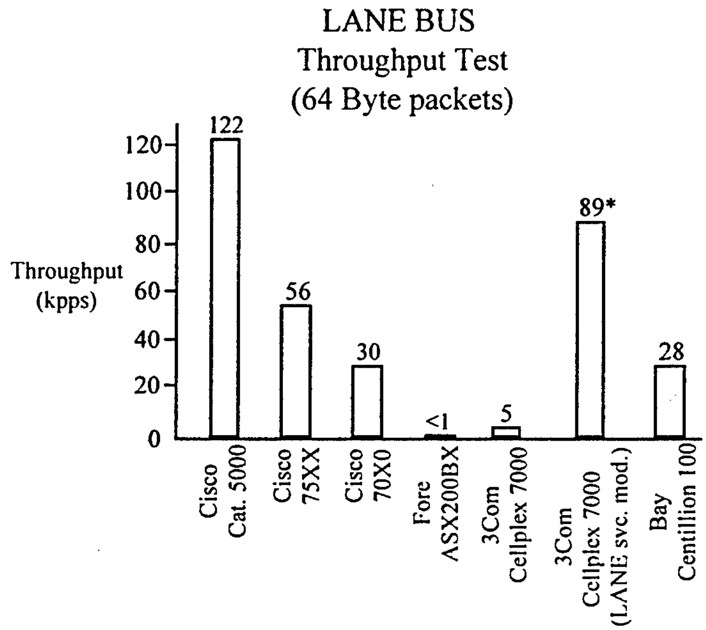
The AWACS application benchmark test addressed the ATM protocol's ability to handle the volume of data between the mission computers and the display consoles. The current method of transmitting the tracks and sensor data to the consoles involved using UDP in the broadcast mode for data that are common to all consoles. This technique allows more consoles to be added to the system with only a minor impact to LAN loading. Since the future AWACS is to be designed for significant numbers of display consoles, this is a key feature that should be investigated for the ATM implementation. The application performance measure was focused on the network, mission computer, and display consoles loading effects.

The test report was divided into: (1) ATM switch, interoperability, and application program test, (2) ATM multicast configuration test, (3) ATM/FDDI network benchmark test, and (4) ATM/FDDI application benchmark test.

6.1. ATM Switch, Interoperability, Application Program Test

Among commercially available products, three ATM switches from Cisco Systems, FORE Systems, and 3Com Corporation were down-selected in this program for the Integrated Battlespace Simulation (IBS) demonstration. The down-selection was based on the trade study that includes functional features, performance data (Figure 6.1.1), technical support, future growth for upgrade, and cost. The Cisco LS-1010 ATM switch was selected in the first place, then the Fore ASX-200BX switch, and the 3Com Cellplex 7000 switch as a backup. Both the Cisco LS-1010 and FORE ASX-200BX switches were implemented for the Advanced AWACS platforms at the ITDL and the Kent OSA

Lab, respectively. The 3Com switch would be used as necessary for ATM port expansion to connect the AWACS platform with the UAV ground station and the advanced fighter station, in the remote (not co-located) laboratory within the ITDL facilities. Figure 6.1 shows a LAN Emulation (LANE) Broadcast and Unknown Server (BUS) throughput comparison among various vendors' ATM switches.



*Module not currently available
(Source: Data Communications, September 1996)

Figure 6.1: ATM LANE BUS Throughput Comparison

There are two different approaches for ATM connection in LAN environments: (1) native mode ATM technology and (2) emulated mode ATM technology. In any case, some protocols (e.g., Intersubnet Protocol) allow for direct communications between different logical subnets as well as within its own logical subnet, while others (e.g., Intrasubnet Protocols) work only within their own logical IP subnet, so they require a separate router for communications between different logical subnets. In the native mode ATM technology, there are three major intrasubnet protocols: (1) Classical IP and ARP over ATM (RFC 1577), (2) IP multicasting MARS over ATM (RFC 1112), (3) Multiprotocol encapsulation over ATM AAL-5 (RFC 1483), and an emerging Internet Engineering Task Force (IETF) intersubnet protocol, i.e., Next Hop Resolution Protocol (NHRP). Note that the Request For Comment (RFC) document is prepared for the IETF standard. Similarly, in the emulated mode ATM technology, there is an intersubnet protocol, ATM LAN emulation, and an emerging ATM Forum intrasubnet protocol, Multi-Protocol Over ATM (MPOA).

Currently, only two major approaches of ATM LANE and classical IP over ATM (RFC 1577) are available as commercial products. Therefore, to establish connectivity among IBS subsystems (e.g., Advanced AWACS, UAV ground station, and fighter stations) the ATM LANE and the Classical IP over ATM approaches were adopted. However, the classical IP over ATM protocol does not support a multicasting (broadcasting) capability, while the ATM LANE protocol does. Thus, the point-to-multipoint Permanent Virtual Circuits (PVC) connections were set up at the ATM switch, then classical IP over ATM were run over Switched Virtual Circuits (SVC) for point-to-point TCP unicast and over permanent virtual circuits for point-to-multipoint UDP multicast.

LAN emulation becomes a standard ATM service that provides interoperability between ATM-based devices and existing legacy LAN-based devices. The function of the LANE protocol is to emulate the local area networks (e.g., Ethernet, Token Ring) on top of an ATM network; in other words, it resolves the Medium Access Control (MAC) addresses into ATM addresses. Since the LANE service presents the same service interface of existing MAC protocols to the network layer, it requires no modifications to higher layer protocols for its operation over an ATM network. The important LANE components include LAN Emulation Client (LEC), LAN Emulation Server (LES), Broadcast and Unknown Server (BUS), and LAN Emulation Configuration Server (LECS).

The switch cell latency is considered insignificant compared with overall system delay. In this section, the interoperability test, LANE BUS throughput test, and software compatibility test between UNIX 4.0 AWACS application program and LANE 1.0 program are described.

6.1.1. Switch Interoperability Test

A. Objective:

To verify an interoperability among different vendors' ATM switches since the three different switches of Cisco Systems, FORE Systems, and 3Com Corporation will be used in one way or another for the Integrated Battlespace Simulation (IBS) demonstration. The Cisco switch and FORE switch (in Kent OSA) were used for Advanced AWACS platforms, and the 3Com switch was used for ATM port expansion, as necessary, depending on a revised network architecture, to connect the AWACS platform with the UAV ground station and advanced fighter station. Since compliance with ATM Forum standards does not necessarily guarantee full ATM interoperability or ease of integration with existing devices, it is worthwhile to verify the interoperability prior to implementation of ATM networks.

B. Approach:

The LAN emulation and Classical IP over ATM configurations were used to determine the switch's interoperability (Figure 6.1.1). ATM LANE service was configured in one of the Cisco Catalyst-5000 LAN switches, their OC-3 uplinks were connected to Cisco LS-1010 ATM switch, then the Cisco ATM switch (network side) was connected through PNNI-0 (IISP) to a 3Com switch or FORE switch (user side). The ATM Address Resolution Protocol (ATMARP) for classical IP over ATM protocol was configured in the Cisco ATM switch. Two SUN workstations (LANE clients) were connected to each ATM switch; one to the Cisco switch and another to the 3Com switch. Two SGI workstations were connected through Fast Ethernet (100Base-T) ports to each of the Cisco Catalyst-5000 LAN switches. The configuration allowed us to test communications between all possible combinations of ATM-attached, LAN-attached, or ATM-LAN attached clients as well as the switch interoperability between different vendors.

C. Test Items:

- Switch interoperability test in LANE and classical IP configurations.
- Communications between ATM-attached, LAN-attached, or ATM LAN clients.

D. Test Procedure:

a) Configure a Cisco Catalyst-5000 LAN switch as LES, BUS, and LECS.
b) Connect the Cisco Catalyst-5000 LAN switch to Cisco ATM switch (via OC-3 link).
c) Configure the Cisco LS-1010 ATM switch as ATMARP.
d) Configure the Cisco switch as IISP network and the 3Com switch as IISP user.
e) Connect the Cisco ATM switch to the 3Com switch.
f) Connect two SUN workstations (LECs) to each of Cisco and 3Com ATM switches.
g) Connect another Cisco Catalyst-5000 LAN switch to Cisco ATM switch (via OC-3).
h) Connect Fast Ethernet to both Cisco Catalyst-5000 LAN switches (via 100Base-T).
i) Connect two SGI workstations to each of the Cisco Catalyst-5000 LAN switches.
j) Verify if the clients between ATM-attached, LAN-attached, or ATM-LAN attached can communicate to each other through LANE and classical IP over ATM services.

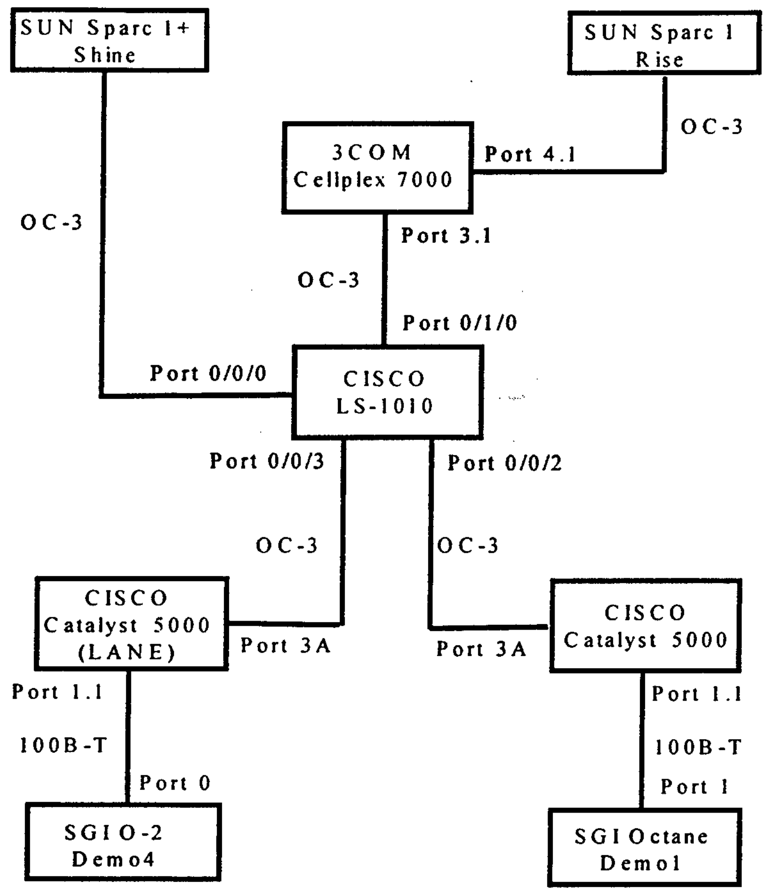


Figure 6.1.1: Switch Interoperability Test Configuration

E. Expected Results:
With LANE and Classical IP over ATM services, all possible combinations of clients should be able to communicate with each other on the ATM interface through the Cisco and 3Com switches.

6.1.2. LAN Emulation BUS Throughput Test

A. Objective:

To verify the Broadcast and Unknown Server (BUS) throughput of various vendors' ATM switches. The BUS is responsible for forwarding all broadcast/multicast and unknown destination unicast frames (received from members of the ELAN) to all members of the ELAN. The LANE BUS throughput test (Figure 6.1.2-1) measures the ability of a BUS to forward frames. According to AWACS requirements, the ATM LAN Emulation (LANE) BUS should be able to meet a minimal throughput of 40 Mbps of multicasting data to multiple display consoles. In addition, since a single BUS may be used for multiple ELANs, the need for a high throughput BUS is increased.

ATM LANE BUS Throughput Test

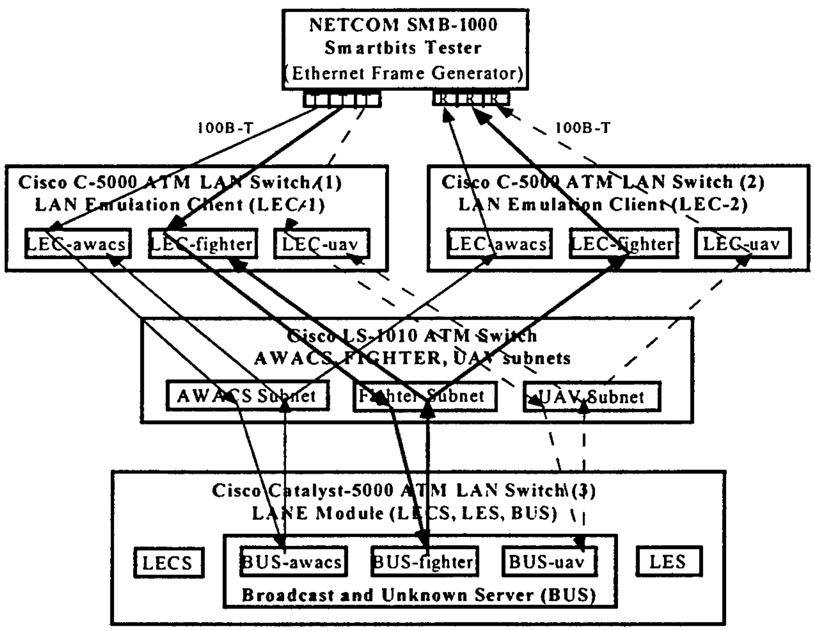


Figure 6.1.2-1: Conceptual Diagram of LANE BUS Function

B. Approach:

The BUS performance strongly influences the overall performance and scalability of LANE networks. In order to avoid the interleaving of cells of different frames during forwarding, which is not permitted for AAL5 Protocol Data Units (PDU), the BUS must serialize the received frames prior to forwarding. This serialization requires a reassembly of incoming frames and a subsequent segmentation of the frames prior to forwarding. As a result, the performance of the SAR on the BUS is the most significant factor affecting overall BUS performance. Given the fact that some BUS implementations perform the SAR in software, while others provide it in hardware, BUS performance varies tremendously.

ATM LANE BUS performance was tested by sending a stream of broadcast frames to the BUS, using an Ethernet frame generator and monitoring the frames forwarded from the BUS. The LANE-capable LAN switches are used to send the frames to the BUS which in turn forwards the frames back to the LAN switches (Figure 6.1.2-2). The SmartBits Analyzer (NetCom) was used for an Ethernet frame generator and its traffic monitor. This test could measure the broadcast forwarding rate over ATM-emulated LANs.

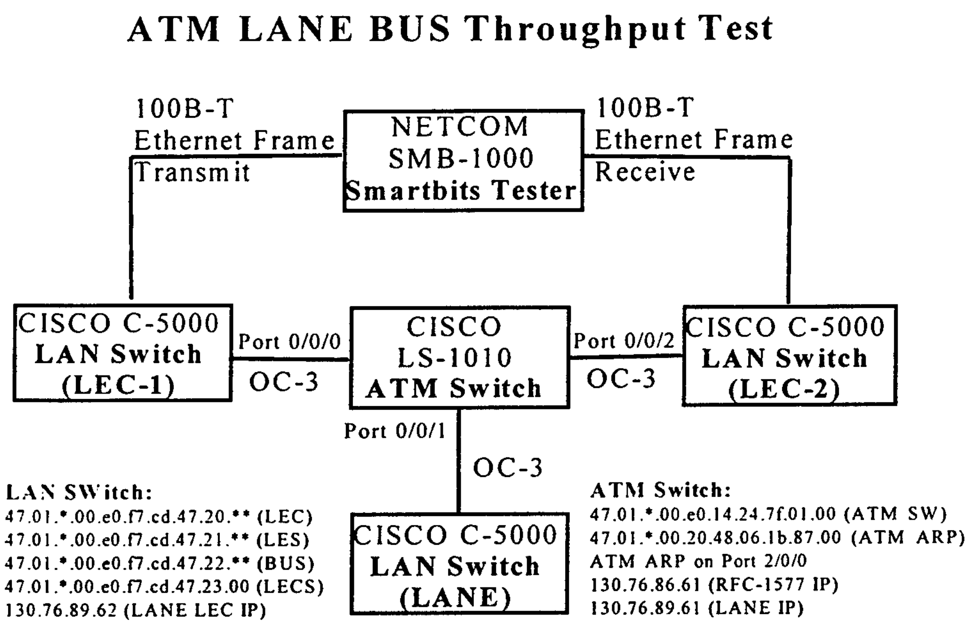


Figure 6.1.2-2: BUS Throughput Test Configuration

C. Test Items:

- LANE throughput

D. Test Procedure:

a) Build an Ethernet frame (64 B) with a broadcast destination MAC address.
b) Configure multiple Ethernet interfaces to transmit the frames at a 100-Mbps rate.
c) Configure multiple Ethernet interfaces to monitor the frames received.
d) Start the Ethernet frame generator on the input ports and the monitor on the output ports.
e) Observe the received packet rate and the transmitted packet rate, both per second.

E. Expected Results:

The ATM switch had a BUS throughput of greater than 60-Mbps broadcast depending on the Maximum Transmission Unit (MTU) size; about 60 Mbps with an MTU size of 64 Byte and 132 Mbps with an MTU size of 1.5 kByte (Figure 6.1.2-3).

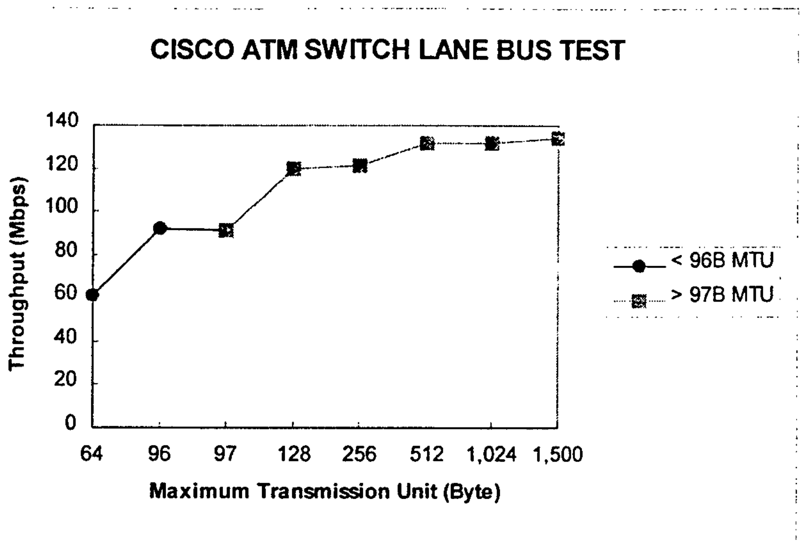


Figure 6.1.2-3: LANE BUS Throughput (Cisco ATM LAN Switch)

6.1.3. AWACS Program Run Test

A. Objective:
To verify a functionality of Advanced AWACS application programs (e.g., mission computer programs) on the DEC Alpha workstation (AWACS platform). The DEC Alpha workstation required digital Unix 4.0 to run ATM LAN Emulation (LANE). Thus, the current digital Unix 3.2x should be upgraded to Unix 4.0. The software compatibility of ATM LANE 1.0 with Unix 4.0 had to be verified for proper AWACS application programs function.

B. Approach:
First of all, the current digital Unix 3.2x was upgraded to Unix 4.0. Then, the Advanced AWACS mission computer programs were operating on ATM switches in LAN Emulation configuration with two DEC Alpha workstations. The AWACS program functionality test (Figure 6.1.3) was performed in point-to-point TCP, point-to-point UDP, and point-to-multipoint UDP multicast modes.

C. Test Items:

- Point-to-point TCP.
- Point-to-point UDP.
- Point-to-multipoint UDP multicast.

D: Test Procedure:

a) Configure ATM switch in LAN emulation mode.
b) Configure two DEC Alpha workstations as LANE clients and designate one as a mission computer and the other as a display console.
c) Verify the ATM LANE network functionality using "PING" test program.
d) Run AWACS application program (Unix 4.0) on a mission computer in a point-to-point TCP mode.
e) Verify a proper functionality of AWACS application program on a display console.
f) Run AWACS application program (Unix 4.0) on a mission computer in a point-to-point UDP mode.
g) Verify a proper functionality of AWACS application program on a display console.
h) Run AWACS application program (Unix 4.0) on a mission computer in a point-to-multipoint UDP multicast mode.
i) Verify a proper functionality of AWACS application program on a display console.

E. Expected Results:
The advanced AWACS mission computer programs were properly operating in the point-to-point TCP, point-to-point UDP, and point-to-multipoint UDP multicast modes over the ATM LAN Emulation configuration with two DEC Alpha workstations.

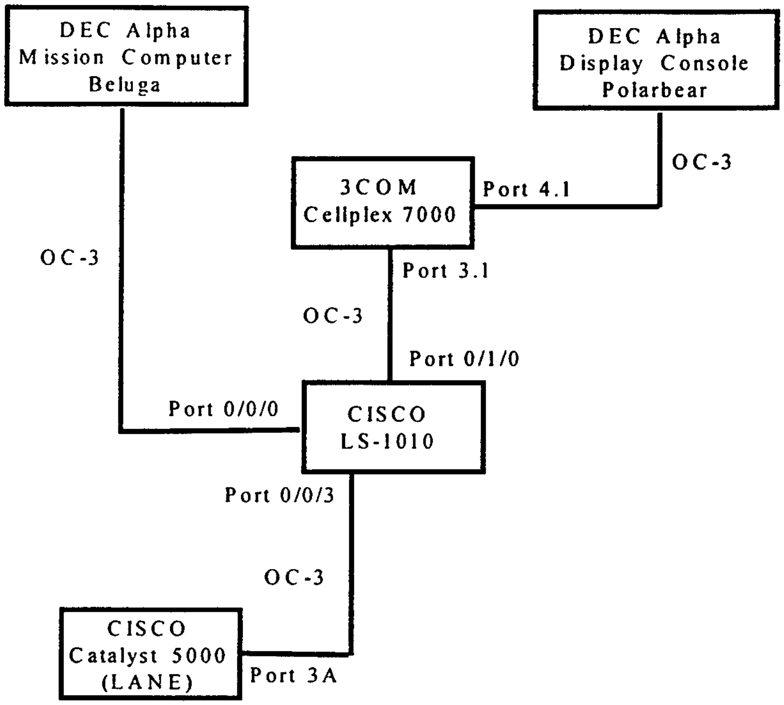


Figure 6.1.3: AWACS Program Run Test Configuration

6.2. ATM Multicast Configuration Test

The Advanced AWACS network architecture and application programs require not only unicast but also multicast capability for the distribution of data. The unicast is based on TCP/IP protocol and is used for operator-related activities such as action entries, alerts/alarms, and database edits between the Mission Computer (MC) and Display Consoles (DC). The multicast is based on UDP/IP protocol and used for common data broadcasting to all consoles within a multicast group on a periodic basis. The Advanced AWACS applications will use a network message to broadcast databases from the MC to all of the DCs, send alarms to specific DCs, or send action entries from DC to MC.

In the network point of view, a multicast allows multiple end systems to receive data from and transmit data to other multiple systems. Such capability is easy to implement in shared-media technologies such as LANs, but not easy in the connection-oriented ATM technology. The analogy in ATM to a multicast LAN group would be a bi-directional multipoint-to-multipoint connection. This obvious solution cannot be implemented when using AAL-5 because, unlike AAL-3/4, it does not allow for interleaving of cells from different AAL-5 packets on a single connection. This means that all AAL-5 packets across a particular connection must be received in sequence at destinations with no interleaving between the cells of different packets on the same connection. The following three potential solutions have been proposed to address the problem; (1) multicasting by multipoint-to-multipoint virtual path connections, (2) multicasting by multicast server, and (3) multicasting by overlaid point-to-multipoint connections.

(1) Virtual Path Connections: In this approach, a multipoint-to-multipoint virtual path links all nodes in the multicast group and each node is given a unique VCI value. The interleaved packets can be identified by the unique VCI value of the source. This mechanism requires a protocol to allocate VCI values to nodes; such a mechanism does not currently exist.

(2) Multicast Server Operation: All nodes set up a point-to-point unidirectional connection with a multicast server. The multicast server is then connected to all nodes through a point-to-multipoint connection. The multicast server receives packets across the point-to-point connection, and then retransmits them across the point-to-multipoint connection, but only after ensuring that the packets are serialized. In this way, cell interleaving is precluded. ATM LAN emulation currently supports only Broadcast and Unknown Server (BUS) operation.

(3) Overlaid Point-to-Multipoint Connections: In this mechanism, each node in the multicast group establishes a point-to-multipoint connection with each of the other nodes in the group. Thus, all nodes can both transmit to and receive from all other nodes. This mechanism requires each node to maintain the total number of all connections within each group, while the multicast server mechanism requires only two connections.

In short, there is no ideal solution yet within ATM for multicast. The higher layer protocols for ATM multicast, using a combination of multicast server and overlaid point-to-multipoint connections, are currently under development in the concept of "Multicast Address Resolution Server (MARS)" by the ATM industry. In the meantime, we will be dependent on the two main configurations of either using a broadcast and unknown server within multiple emulated LANs in LAN emulation configuration or using multiple point-to-multipoint PVC connections on top of Classical IP over ATM point-to-point Switched Virtual Circuits (SVC) connections.

6.2.1. ATM LAN Emulation-Based Multicast Test

A. Objective:
To verify an ATM switch's capability of multicasting with a required data rate from a mission computer to multiple display consoles. The multicast is based on UDP/IP protocol and is used for common data broadcasting to all consoles within a multicast group on a periodic basis.

B. Approach:
The ATM LANE can support multiple independent Emulated LAN (ELAN) networks. Membership of an end system in any of the emulated LANs is independent of the physical location of the end system. Since LAN emulation connectivity is defined at the Medium Access Control (MAC) layer, upper layer protocols of LAN applications remain unchanged when the ATM or LAN-attached devices join emulated LANs. With multiple emulated LANs and the LANE's broadcasting capability, ATM multicasting was demonstrated. The ATM LANE operation procedure is shown in Figure 6.2.1-1.

C. Test Items:

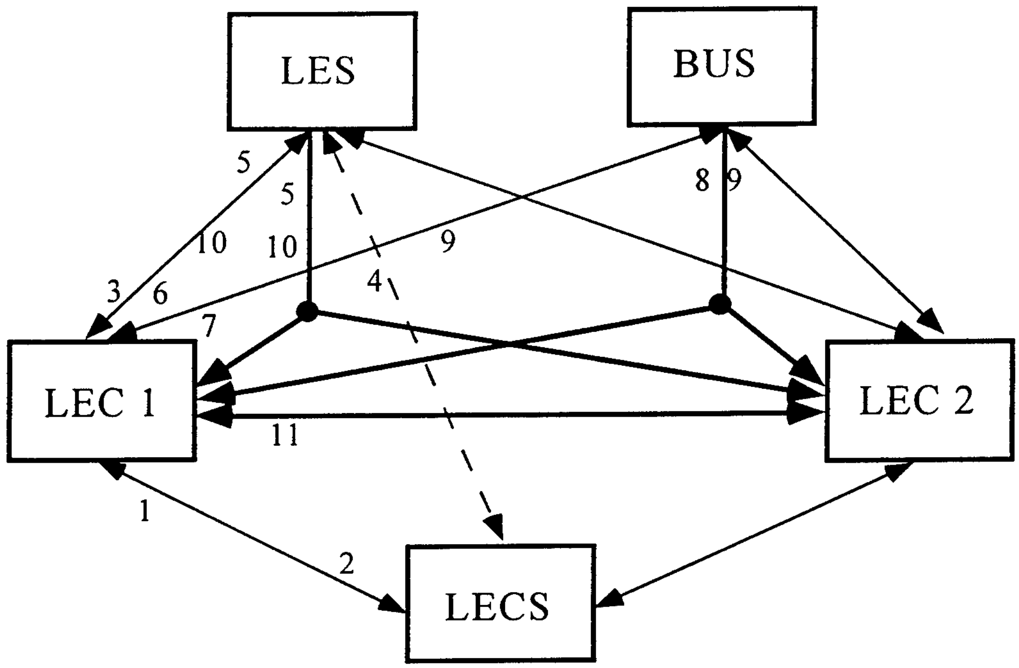
- Multiple emulated LANs using ATM LANE.

D. Test Procedure:

a) Connect Cisco ATM switch to Catalyst-5000 LAN Switch with an OC-3c link.
b) Configure the Cisco Catalyst-5000 LAN Switch as LEC, LES, BUS, and LECS.
c) Configure multiple LECs on the ATM interface.
d) Configure a LECS, LES, and BUS for multiple ELANs on the ATM interface.
e) Allow the clients to connect to the LANE services.
f) Verify if the client can multicast to some of the clients.

E. Expected Results:
The multicast configuration with multiple ATM emulated LANs was properly set up as shown in Figure 6.2.1-2. The ATM multicast functionality was properly verified.

ATM LAN Emulation Operation Procedure



A. Initialization and Configuration

0. Upon power up, LEC registers its own ATM address
1. LEC requests to join ELAN
2. LECS identifies LES and provides the LES identification to LEC

B. Joining and Registering with LES

3. LEC registers with LES
4. LES verifies with LECS that LEC is allowed to join the ELAN
5. LES allows or does not allow the LEC to join the ELAN

C. Finding and Joining BUS

6. LEC sends LE-ARP packets to LES for finding the BUS ATM address
7. LEC sets up the multicast-send connection to BUS
8. BUS sets up the multicast-forward connection to LEC

D. Data Transfer

9. BUS floods a data packet to all LECs on the ELAN
10. LEC resolves an ATM address of the unknown destination LEC
11. LEC sends BUS LANE flushing message and then starts data transfer

Figure 6.2.1-1: ATM LAN Emulation Operation Concept

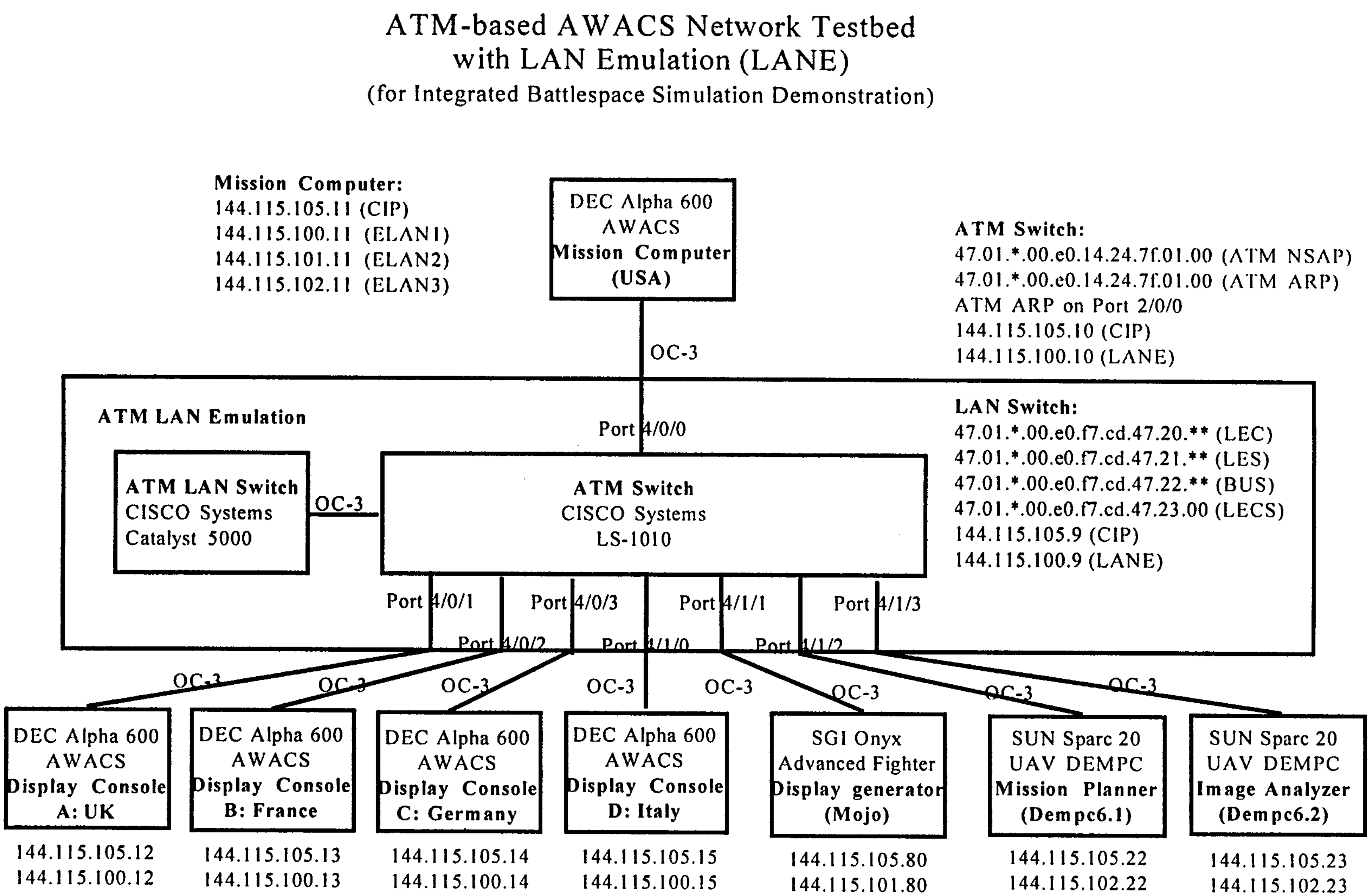


Figure 6.2.1-2: Multicast Configuration with Multiple ATM Emulated LANs

6.2.2. ATM Classical IP-Based Multicast Test

A. Objective:
To verify an ATM switch's capability of multicasting with a required data rate from a mission computer to multiple display consoles. The multicast is based on UDP/IP protocol and is used for common data broadcasting to all consoles within a multicast group on a periodic basis.

B. Approach:
The alternative approach to ATM multicasting is to use multiple point-to-multipoint Permanent Virtual Circuits (PVC) connections on top of Classical IP over ATM point-to-point Switched Virtual Circuits (SVC) connections. In this configuration, the multiple point-to-multipoint PVC connections link all nodes in the multicast group, and each node is given a unique VPI/VCI value. The operation procedure is shown in Figure 6.2.2-1.

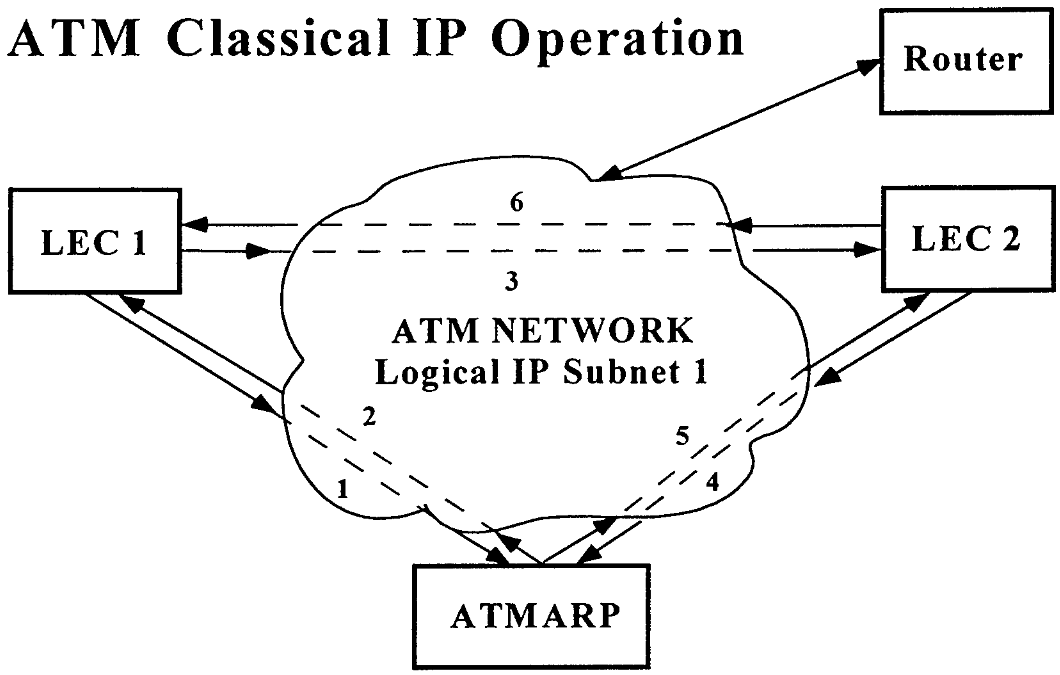
C. Test Items:

- Multiple point-to-multipoint Permanent Virtual Circuits (PVC).

D. Test Procedure:

a) Configure the Cisco ATM switch in a single point-to-multipoint connection.
b) Select the ATM interfaces (ports) to be configured.
c) Configure a VPI/VCI of the PVC connection at the root port.
d) Configure multiple VPIs/VCIs of the PVC connections at the leaf port.
e) Configure multiple point-to-multipoint connection.
f) Verify the PVC between ATM switch connections.
g) Verify that the client can multicast to some of the clients.

E. Expected Results:
The multicast configuration with multiple Permanent Virtual Circuits (PVC) on top of Classical IP over ATM Switched Virtual Circuits (SVC) connections was properly set up, as shown in Figure 6.2.2-2. The ATM multicast functionality was properly verified.



1. The sender (LEC-1) sends an ATMARP request to ATMARP Server on the logical IP subnet to find an ATM address of the receiver (LEC-2).
2. ATMARP returns a receiver's ATM address to the sender.
3. LEC-1 starts to send the message to LEC-2.
4. When LEC-2 receives the first packet, it also sends an ATMARP request to ATMARP Server to find the location of the sender (LEC-1).
5. ATMARP returns a sender's ATM address to the receiver.
6. LEC-1 and LEC-2 can directly communicate.

Figure 6.2.2-1: Classical IP over ATM Operation Concept

ATM-based AWACS Network Testbed with Classical IP and Multicast PVC's

(for Integrated Battlespace Simulation Demonstration)

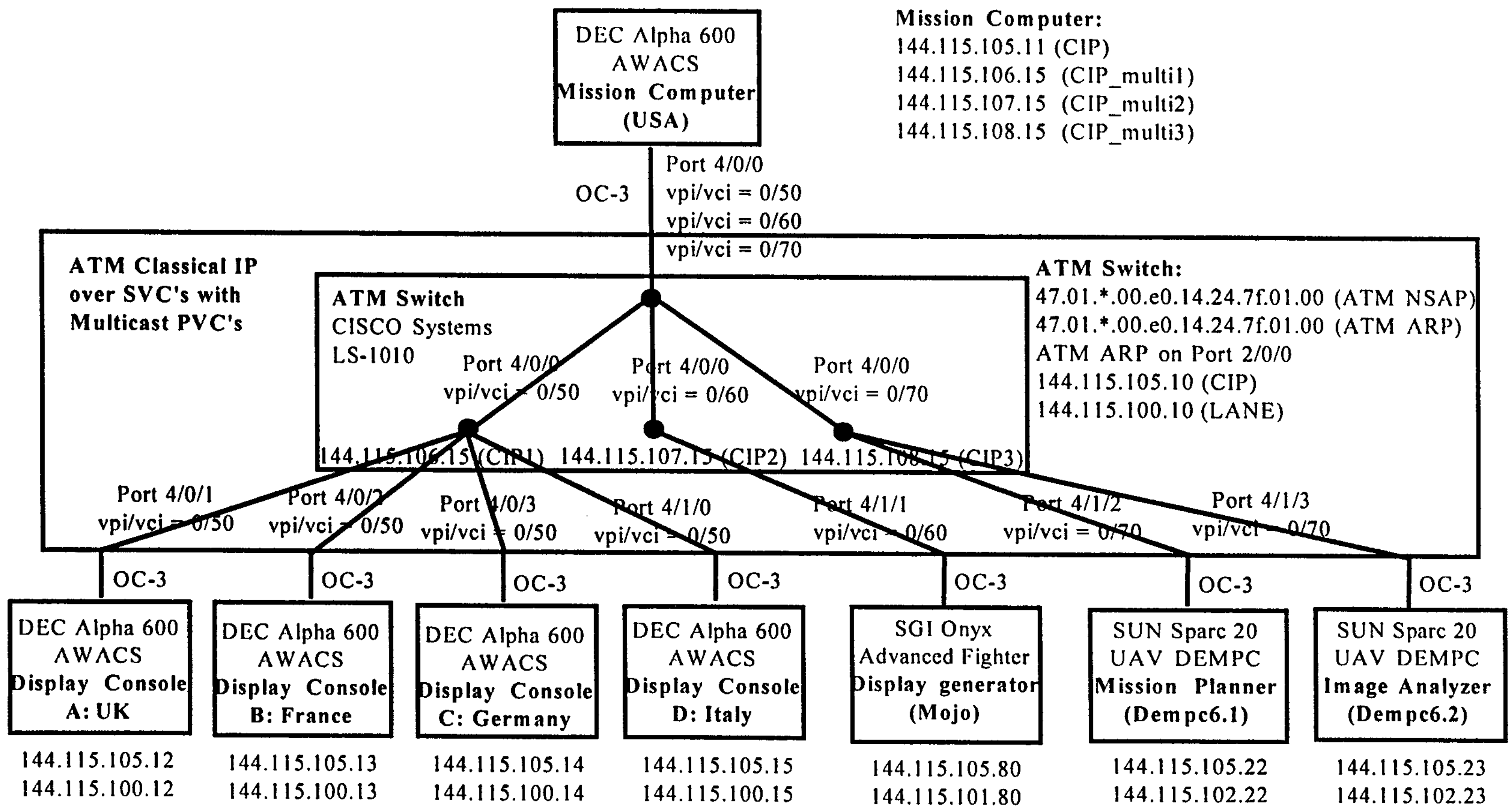


Figure 6.2.2-2: Multicast Configuration with Classical IP and PVCs

6.3. ATM/FDDI Network Benchmark Test with AWACS Platforms

The existing Advanced AWACS network architecture is based on FDDI; the proposed architecture uses ATM over OC-3c (155 Mbps). While the interim and the final demonstrations are the most visible tasks of this program, the quantitative ATM performance measures are also important. Generally, throughput and latency are the two most important network architecture metrics. Within the context of the Advanced AWACS network architecture, point-to-point and multicast throughputs are of particular interest.

The throughput test was performed for three distinct network implementations: (1) ATM with classical IP (RFC 1577) and PVCs for multicast, (2) ATM with LANE, and (3) FDDI. Each of these three network implementations was tested in three distinct configurations: (1) Point-to-point TCP duplex, (2) Point-to-multipoint UDP simplex, and (c) Simultaneous TCP duplex and UDP simplex.

6.3.1. Network Benchmark Test Tools

Benchmarks are tests commonly used to predict the performance of an unknown system. The popular network performance benchmarks can be achieved by using public domain software tools. Different groups of test tools exist - from simple software programs to complex network analyzers - which could be used for monitoring, diagnosis, and performance measurement of a system or subsystem. Among various tools available for network monitoring and performance tests, the following tools were chosen especially for ATM-based networks: Internet Control Message Protocol (ICMP) ECHO_REQUEST and ECHO_RESPONSE (i.e., "PING"), NTTCP, NETPERF, NETTEST, and NETCONFIG.

A. PING and BING:

The PING is the most common network monitoring tool that can be used for network testing, measurement and management. It utilizes the ICMP's ECHO_REQUEST datagram to elicit an ECHO_RESPONSE from a host or gateway. The ECHO_REQUEST datagram has an IP and ICMP header, followed by an 8-byte timestamp, and then an arbitrary number of "pad" bytes used to fill out the packet. To initiate the ECHO service, a sender host sends the ICMP data unit with the address of the destination host and the IP address filed. The host can be its name or its IP address.

The PING continually sends one datagram per second, and prints one line of output for every ECHO_RESPONSE returned. If the -c count option is given, only that number of requests is sent. No output is produced if there is no response. Round-trip times and packet loss statistics are computed. If duplicate packets are received, they are not included in the packet loss calculation, although the round trip time of these packets is used in calculating the minimum/average/maximum round-trip time numbers. When the specified number of packets have been sent (and received) or if the program is terminated with an interrupt (SIGINT), a brief summary is displayed. When not using the -f (flood)

option, the first interrupt, usually generated by control-C or DEL, causes PING to wait for its outstanding requests to return. It will wait no longer than the longest round trip time encountered by previous, successful pings. The second interrupt stops PING immediately.

The PING will report duplicate and damaged packets. Duplicate packets should never occur, and seem to be caused by inappropriate link-level retransmission. Duplicates may occur in many situations and are rarely (if ever) a good sign, although the presence of low levels of duplicates may not always be cause for alarm. Damaged packets are obviously serious cause for alarm and often indicate broken hardware somewhere in the PING packet's path (in the network or in the hosts).

There are modified PING tools such as BING (Bandwidth PING). The BING is a point-to-point bandwidth measurement tool, based on PING. The BING determines the real throughput on a link by measuring ICMP echo requests round-trip times for different packet sizes for each end of the link. It allows a host A to remotely measure the throughput between remote links L1 and L2, two extremities of a point-to-point link. By measuring the round-trip time (rtt) between A and L1, and rtt between A and L2, the time between L1 and L2 can be deduced. If we do that for two different packet sizes, we can compute the real throughput (as opposed to available or average throughput) of the link.

B. NTTCP:

NTTCP is a benchmarking tool for determining TCP and UDP performance between two systems. NTTCP times the transmission and reception of data between two systems using the UDP or TCP protocols and it tests the bulk transfers with variations of number of buffers and sizes. It differs from common ``blast" tests, which tend to measure the remote inetd (internet service daemon) as much as the network performance, and which usually do not allow measurements at the remote end of a UDP transmission.

For testing, the transmitter should be started with -t and -s after the receiver has been started with -r and -s. Tests lasting at least tens of seconds should be used to obtain accurate measurements. Graphical presentations of throughput versus buffer size for buffers ranging from tens of bytes to several "pages" can illuminate bottlenecks. NTTCP can also be used as a "network pipe" for moving directory hierarchies between systems when routing problems exist or when the use of other mechanisms is undesirable.

C. NETPERF:

Netperf is a networking benchmark tool developed by Hewlett-Packard that allows measurement of various aspects of networking performance. The current version is focusing on bulk data transfer throughput (bandwidth) and request-response (latency) tests for TCP and UDP using the Berkeley Socket interface. This is widely used by the ATM industry as a standard benchmarking tool. There are optional tests available to measure the performance of UNIX Domain Sockets, FORE ATM API, and HP HIPPI link level access.

The most common test is to measure bulk data transfer performance (throughput). This is referred to as TCP stream or unidirectional UDP stream performance. The TCP stream performance test will perform a 10-second test between the local host and the remote host. The UDP stream performance test is similar to a TCP stream test. One difference is that the transmit size can not be larger than the smaller of the local and remote socket buffer sizes. The second test is to measure request-response or transaction performance. A transaction is defined as the exchange of a single request and a single response. From a transaction rate, one can infer one way and round-trip average latency.

6.3.2. TCP Performance Test

A. Objective:
To measure the throughput of the Point-to-Point (P-P) TCP duplex configuration over each network implementation. This configuration demonstrates multiple point-to-point TCP connections between one Mission Computer (MC) and four Display Consoles (DC). Specifically, there are no multicast communications included in this configuration.

B. Approach:
The test uses the Netperf and/or NTTCP configured as "server" on the MC and as "client" on the DCs. The parameters are DC receive/transmit buffer size, MC transmit/receive buffer size, and MC TCP transmit message size. Multiple TCP connections between the MC and DCs will be established, and corresponding throughput measured.

C. Test Items:

- Throughput at MC/DCs.

D. Test Procedure:

a) Use Netperf and/or NTTCP on MC (server) and DCs (client).
b) Vary the transmit buffer sizes on the MC and DCs.
c) Vary the receive buffer sizes on the MC and DCs.
d) Vary the transmit message sizes on the MC.
e) For each combination, observe and record throughput at the MC and DCs.
f) For receive/transmit socket buffer sizes of 1, 2, 4, 8, 16, 32, 64, and 128K bytes on the MC and DCs.
g) For MC transmit message sizes of 1, 10, 25, 50, 100, 500K, 1, 5, 10M bytes.
h) Measure the throughput with P-P TCP connections for each DC.

E. Expected Results:
All tests were performed in three different network configurations: FDDI, ATM LANE, ATM Classical IP (CIP), and multicast PVCs. The most common test is to measure bulk data transfer performance (throughput) in either a TCP stream or a unidirectional UDP stream. Figures 6.3.2-1 through 6.3.2-10 summarize the TCP_STREAM and TCP_REQUEST/RESPONSE test performance in three different configurations.

Figures 6.3.2-1 to 6.3.2-4 show the TCP_STREAM throughput test performance. The maximum throughputs in the TCP_STREAM test of FDDI, ATM LANE, and ATM CIP were 96 Mbps, 108 Mbps, and 118 Mbps, respectively, over variable message size. The throughput increased with the receive and transmit socket buffer size, but it is relatively insensitive to the message size when it is bigger than the Maximum Transmission Unit (MTU). The second test is to measure a transaction rate performance. A transaction is defined as the exchange of a single Request/Response (RR). Figures 6.3.2-5 to 6.3.2-8 show TCP_RR test results. The round-trip delay can be estimated from a transaction rate; with a 1 KByte message, 0.63 ms (FDDI), 0.58 ms (ATM LANE), and 0.60 ms (ATM CIP), all for TCP traffic.

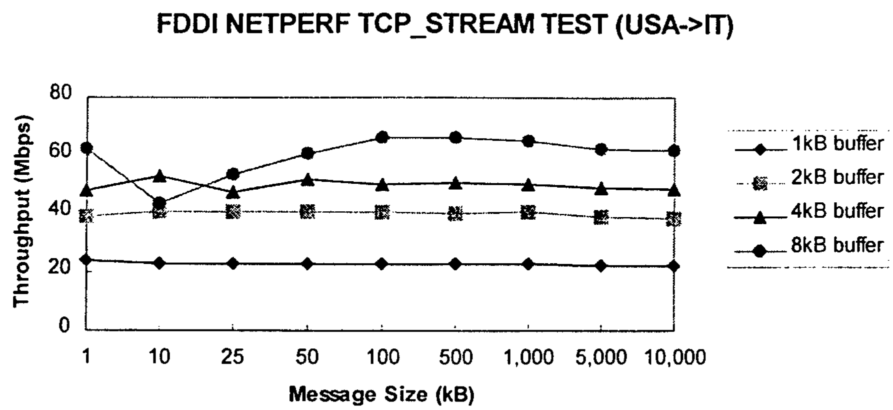


Figure 6.3.2-1(a): FDDI TCP Performance

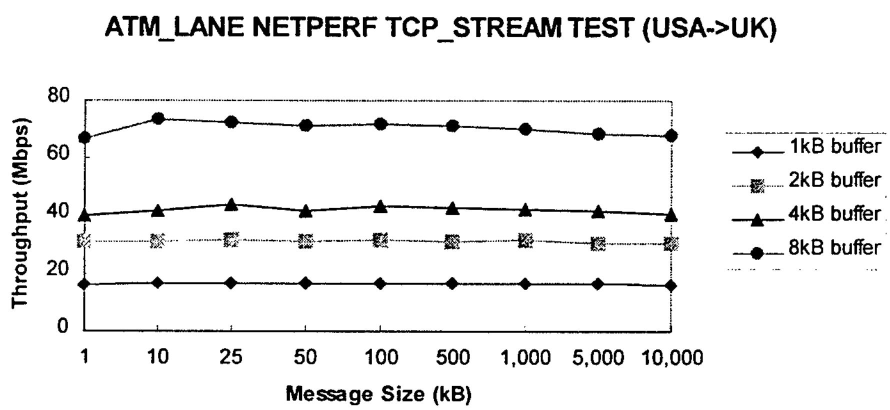


Figure 6.3.2-1(b): ATM LANE TCP Performance

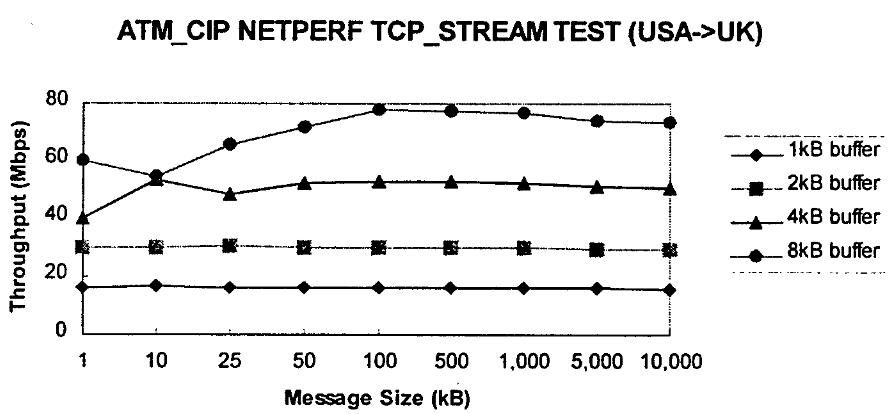


Figure 6.3.2-1(c): ATM CIP TCP Performance

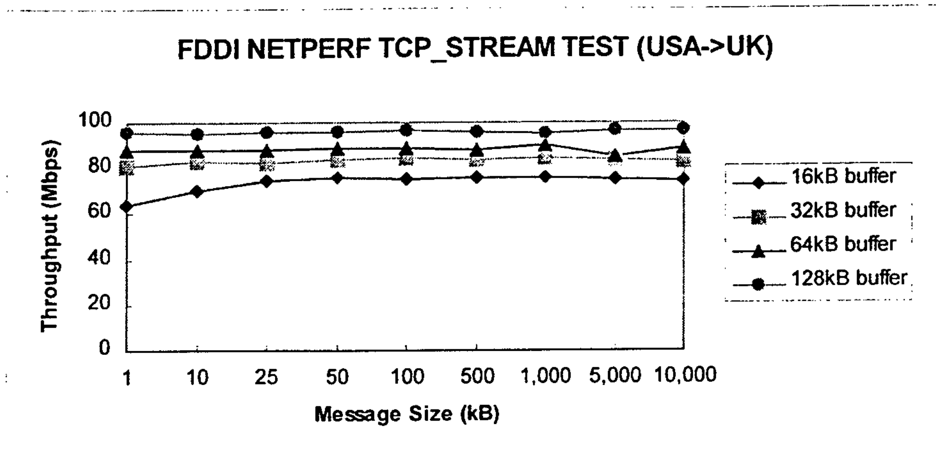


Figure 6.3.2-2(a): FDDI TCP Performance

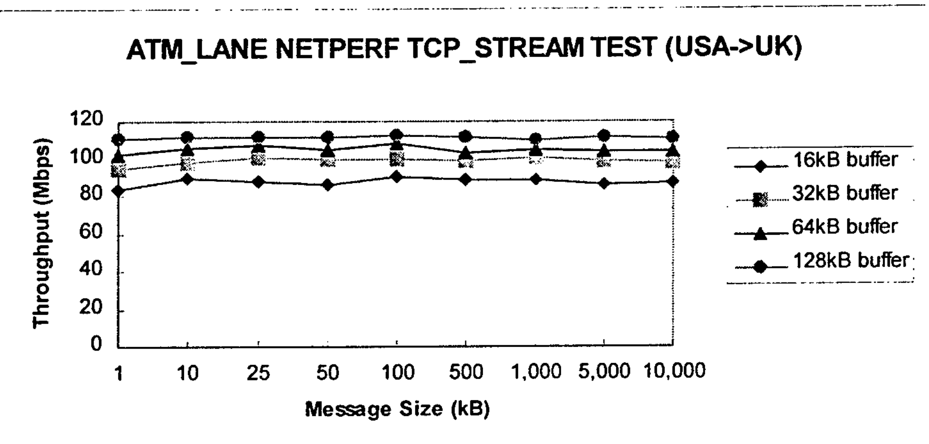


Figure 6.3.2-2(b): ATM LANE TCP Performance

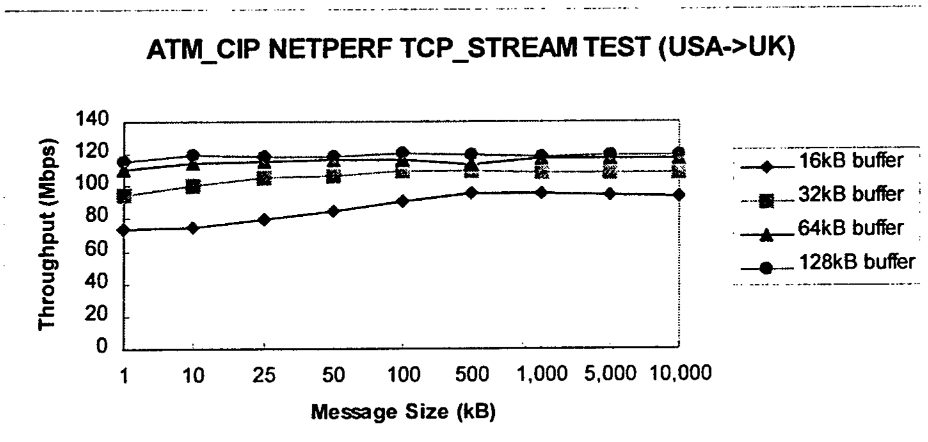


Figure 6.3.2-2(c): ATM CIP TCP Performance

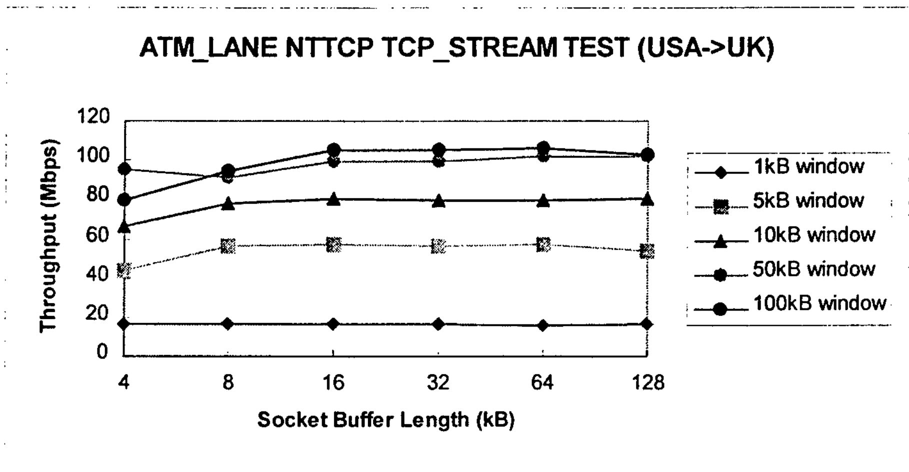


Figure 6.3.2-3(a): ATM LANE TCP Performance (by NTTCP)

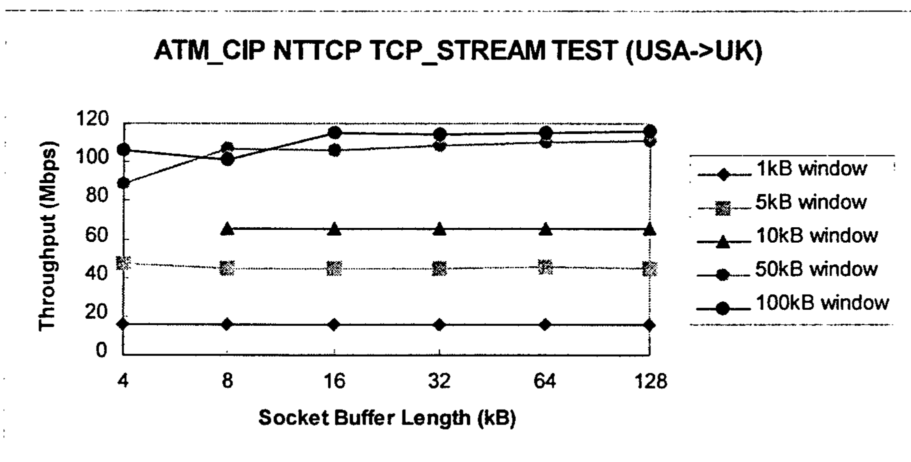


Figure 6.3.2-3(b): ATM CIP TCP Performance (by NTTCP)

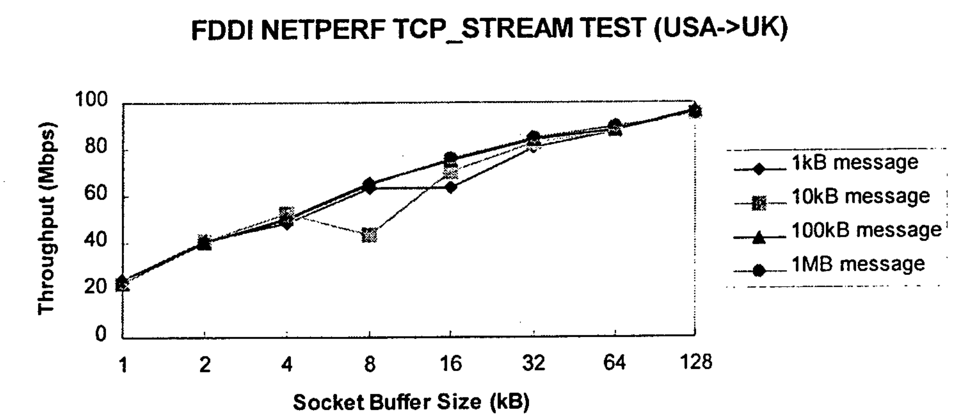


Figure 6.3.2-4(a): FDDI TCP Performance

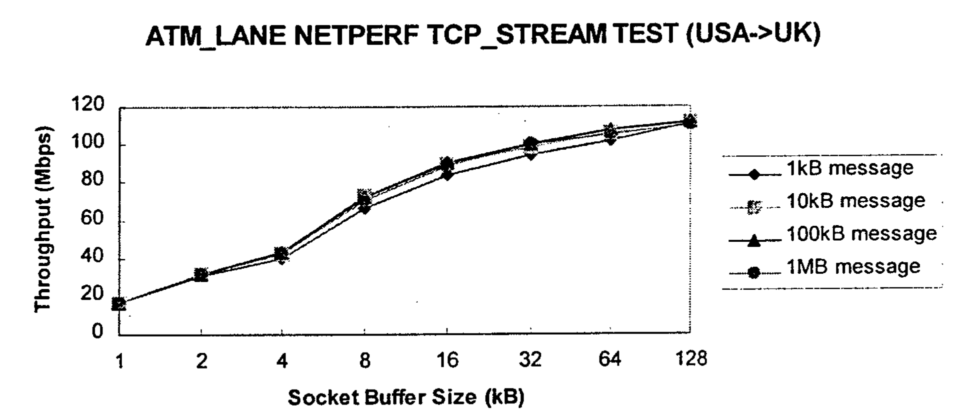


Figure 6.3.2-4(b): ATM LANE TCP Performance

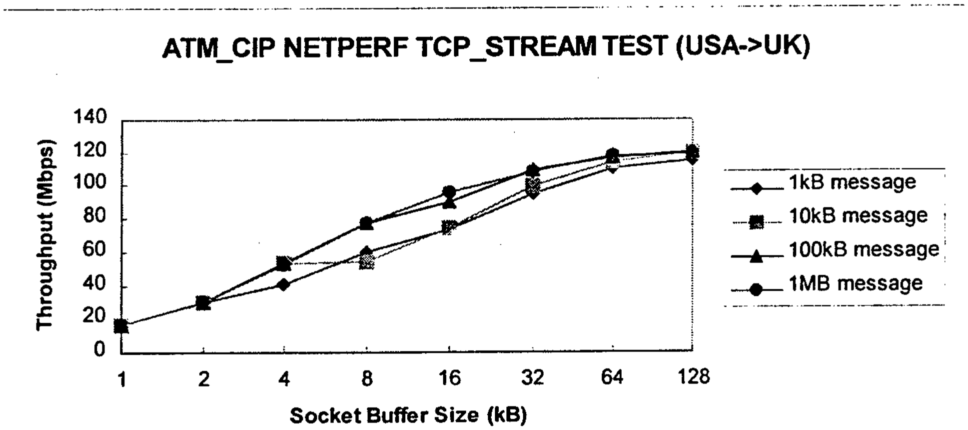


Figure 6.3.2-4(c): ATM CIP TCP Performance

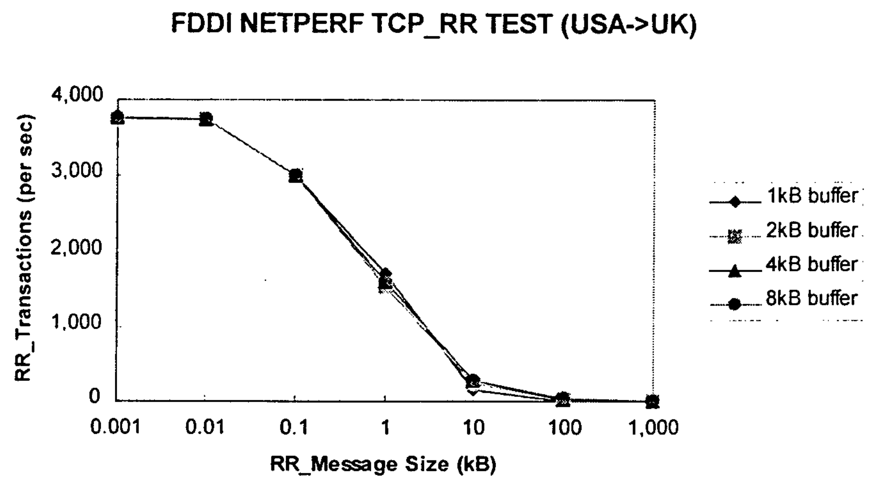


Figure 6.3.2-5(a): FDDI TCP Performance

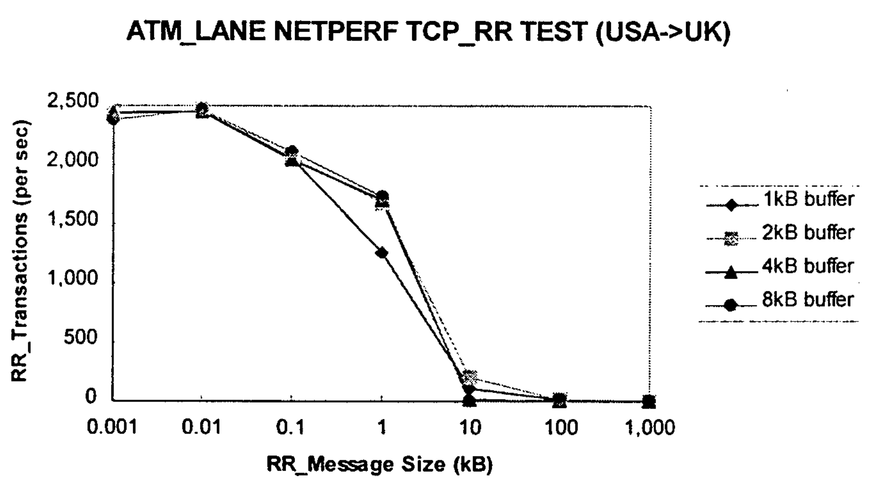


Figure 6.3.2-5(b): ATM LANE TCP Performance

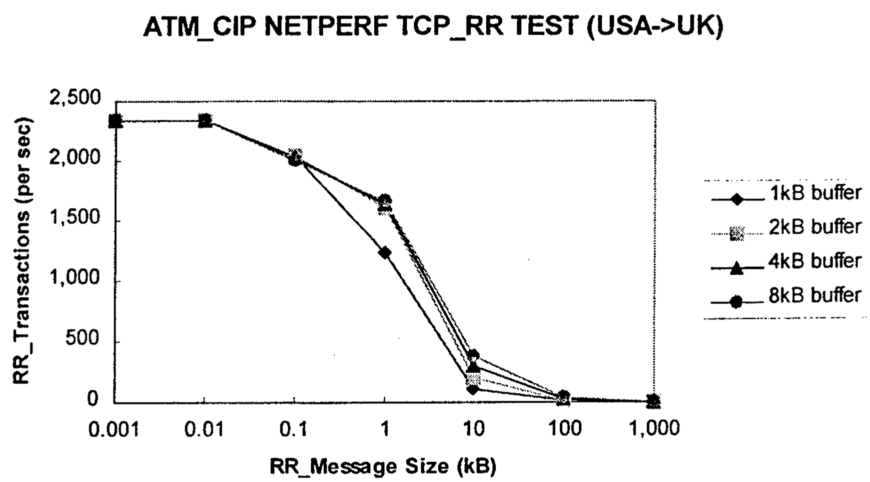


Figure 6.3.2-5(c): ATM CIP TCP Performance

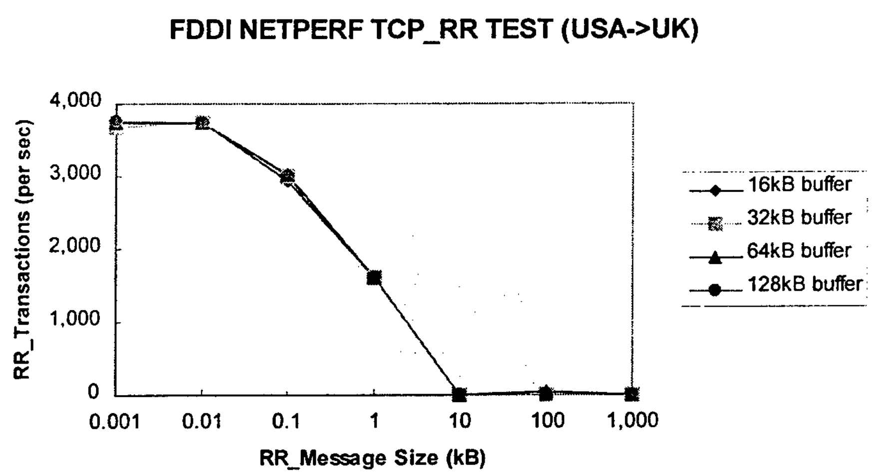


Figure 6.3.2-6(a): FDDI TCP Performance

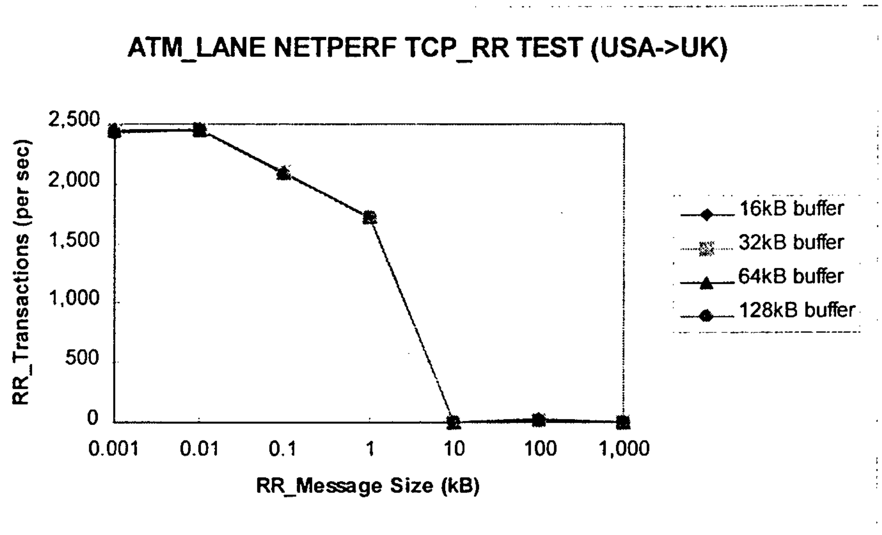


Figure 6.3.2-6(b): ATM LANE TCP Performance

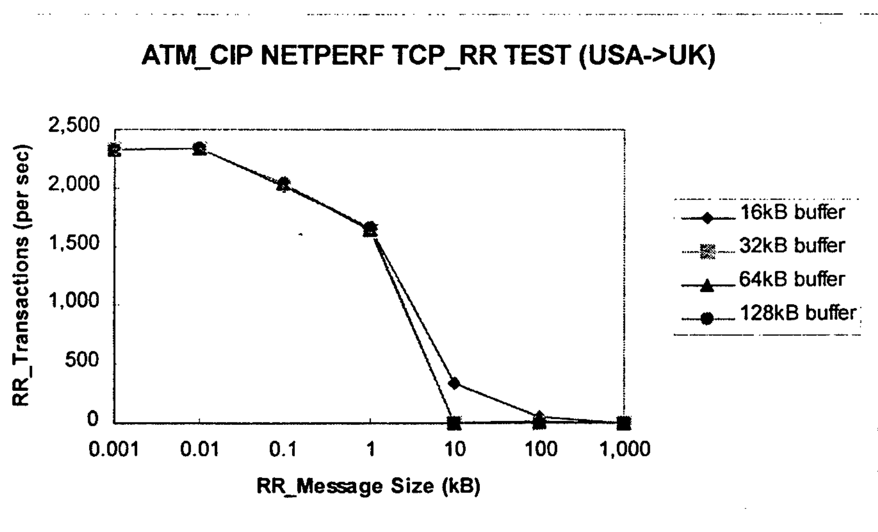


Figure 6.3.2-6(c): ATM CIP TCP Performance

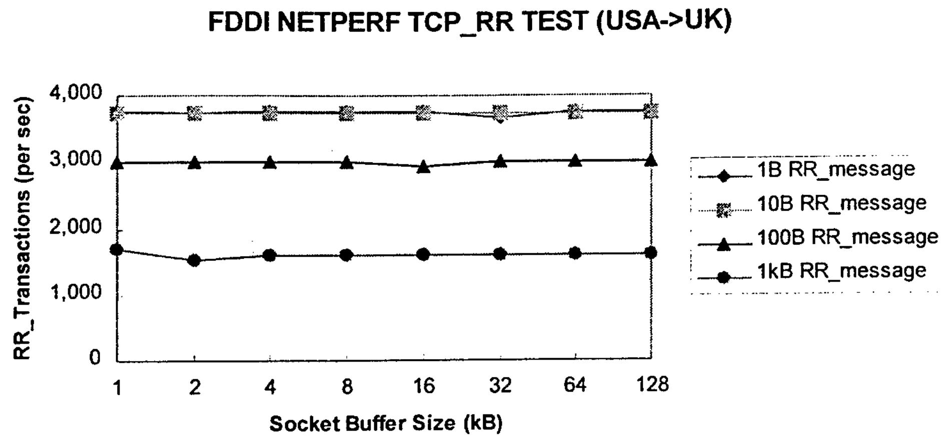


Figure 6.3.2-7(a): FDDI TCP Performance

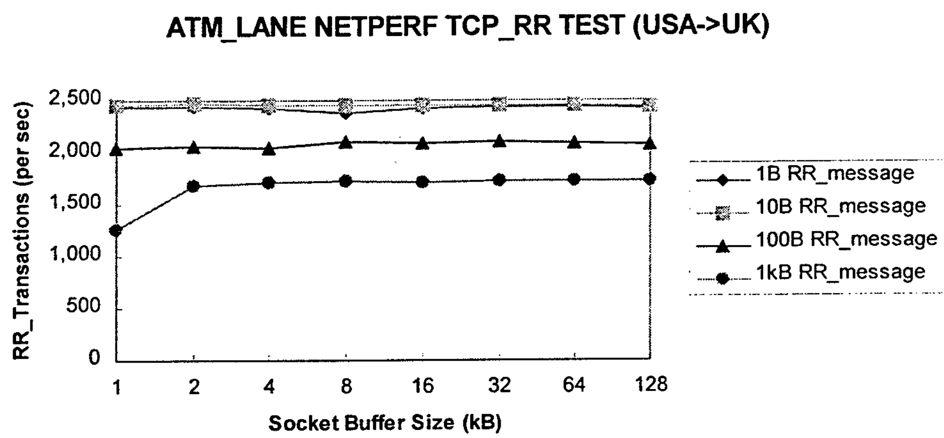


Figure 6.3.2-7(b): ATM LANE TCP Performance

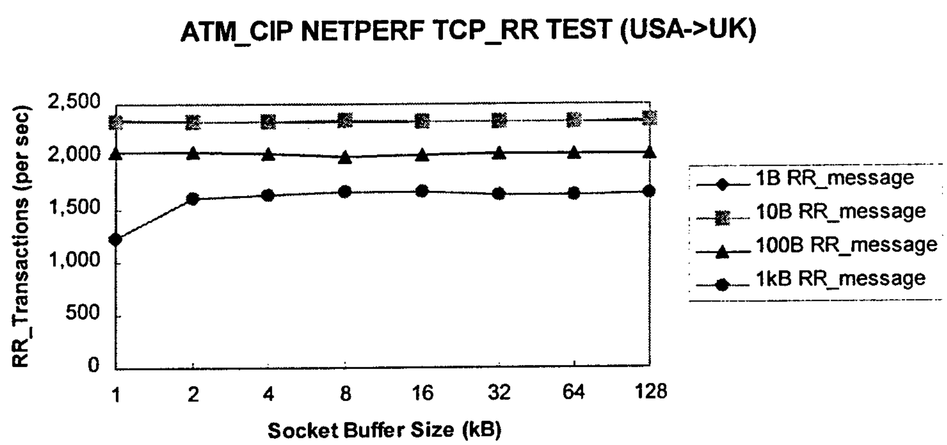


Figure 6.3.2-7(c): ATM CIP TCP Performance

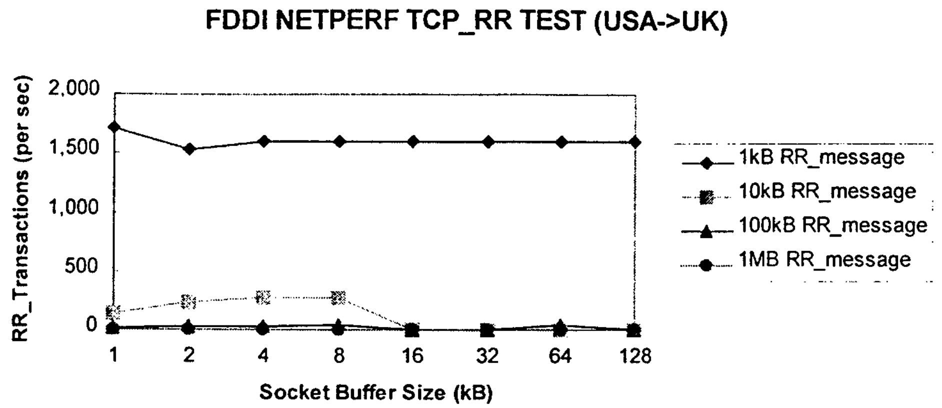


Figure 6.3.2-8(a): FDDI TCP Performance

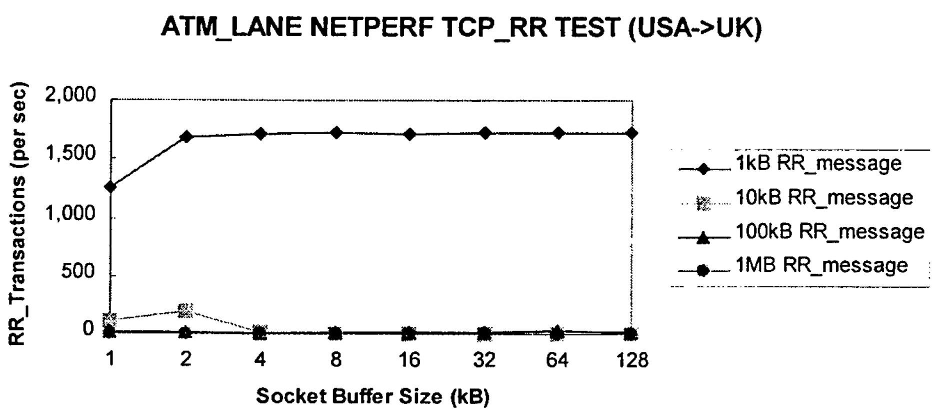


Figure 6.3.2-8(b): ATM LANE TCP Performance

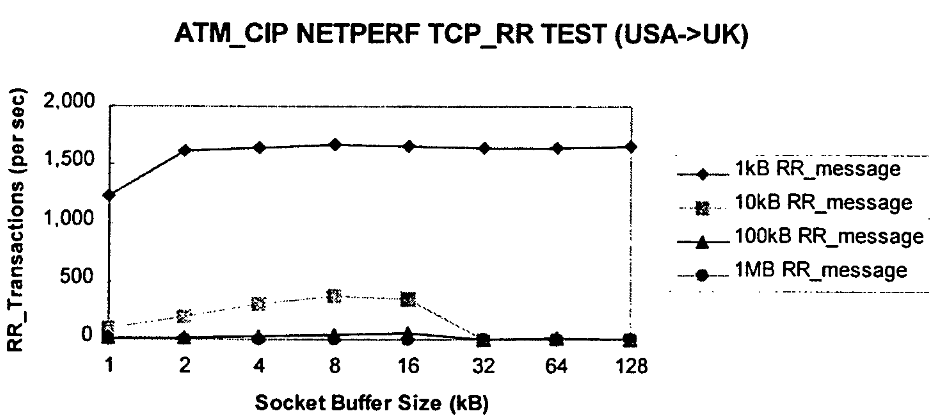


Figure 6.3.2-8(c): ATM CIP TCP Performance

6.3.3. UDP Performance Test

A. Objective:

To measure the throughput of the Point-to-Point (P-P) UDP simplex and Point-to-Multipoint (P-M) UDP simplex configuration over each network implementation. The point-to-multipoint configuration demonstrates an UDP communication stream from one Mission Computer (MC) to four Display Consoles (DC).

B. Approach:

With the same approach as section 6.3.2, the parameters will be DC receive buffer size, MC transmit buffer size, and MC UDP transmit message size. A single UDP distribution from the MC to the DCs will be established and corresponding throughput measured.

C: Test Items:

- Throughput at MC/DCs.

D. Test Procedure:

a) Use Netperf and/or NTTCP on MC (server) and DCs (client).
b) Vary the transmit buffer sizes on the MC and DCs.
c) Vary the receive buffer sizes on the MC and DCs.
d) Vary the transmit message sizes on the MC.
e) For each combination, observe and record throughput at the MC and DCs.
f) For receive/transmit socket buffer sizes of 1, 2, 4, 8, 16, 32, 64, and 128K bytes on the MC and DCs.
g) For MC transmit message sizes of 1, 10, 25, 50, 100, 500K, 1, 5, 10M bytes.
h) Measure the throughput with P-P UDP and P-M UDP connections for each DC.

E. Expected Results:

All tests were performed in three different network configurations: FDDI, ATM LANE, ATM Classical IP (CIP) and multicast PVCs. The throughput of the Point-to-Point (P-P) UDP simplex was measured. The NTTCP and NETPERF do not allow for the Point-to-Multipoint (P-M) UDP simplex test. For UDP_STREAM test, FDDI can best handle UDP traffic irrespective of socket buffer size and without considering delay time variation. ATM LANE and CIP may require a proper delay time between UDP traffics. TCP and UDP round-trip delay time was slightly faster in ATM (LANE or CIP) than delay time in FDDI, but all were within the AWACS requirement of less than 10 ms, as long as the message size was less than 10 kByte. Figures 6.3.3-1 to 6.3.3-6 summarize the UDP_STREAM and UDP_REQUEST/RESPONSE performance in three configurations.

The UDP stream performance test is similar to a TCP stream test. The one difference is that the transmit size can not be larger than the smaller of the local and remote socket buffer size. The UDP_STREAM test in Figure 6.3.3.-1(a), (b), (c) showed that FDDI outperformed ATM, irrespective of socket buffer size. Even with the transmit size constraint, it still may need to control the interval between packets to keep

UDP_STREAM from running away with all the resources of the ATM network. Note that the delay between sending packets was not counted in this UDP throughput test; this can be a subject for further study. The UDP transaction rate performance is shown in Figures 6.3.3-4 to 6.3.3-6. Similarly, the average round-trip delay can be estimated from a transaction rate: 0.61 ms for UDP in all cases with a 1 KByte message.

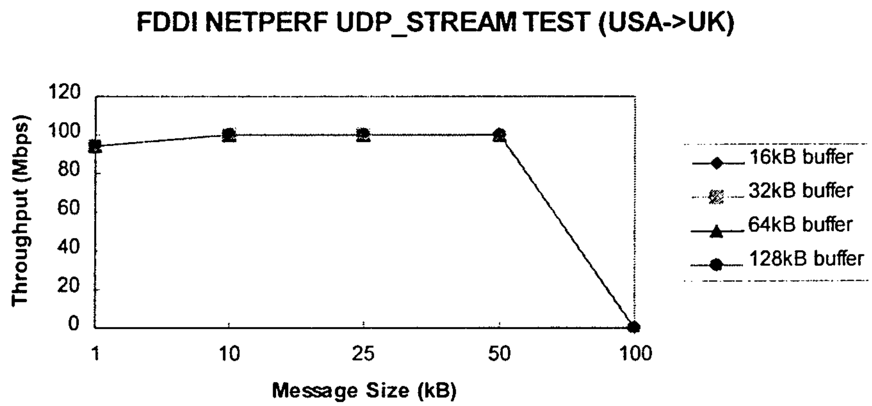


Figure 6.3.3-1(a): FDDI UDP Performance

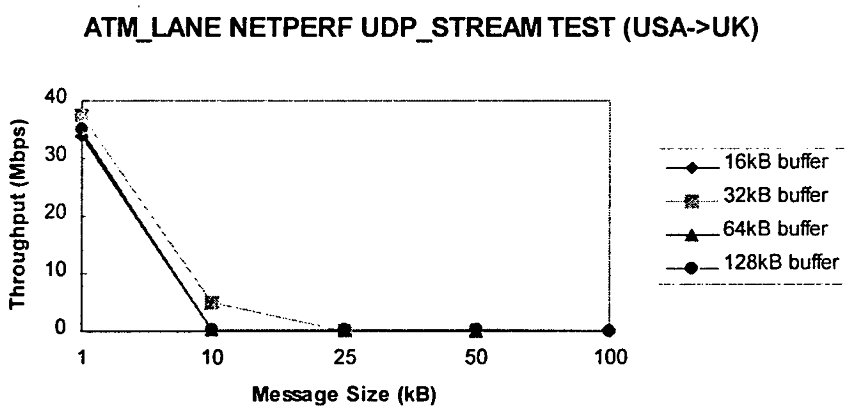


Figure 6.3.3-1(b): ATM LANE UDP Performance

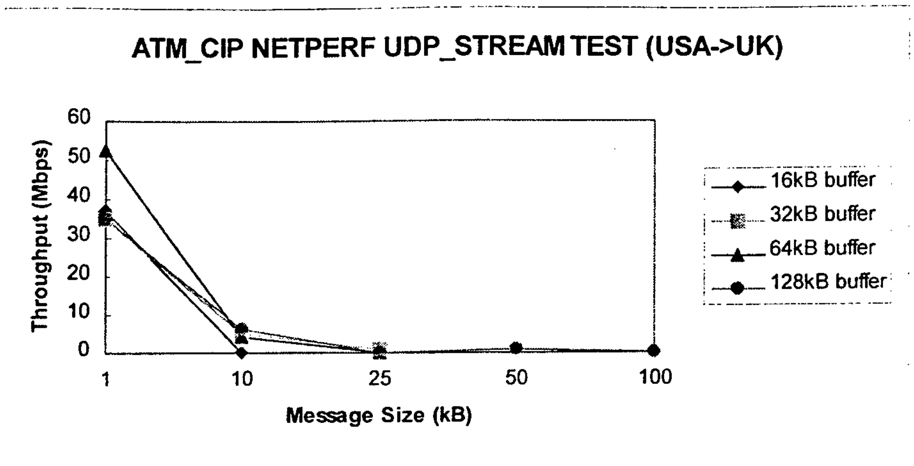


Figure 6.3.3-1(c): ATM CIP UDP Performance

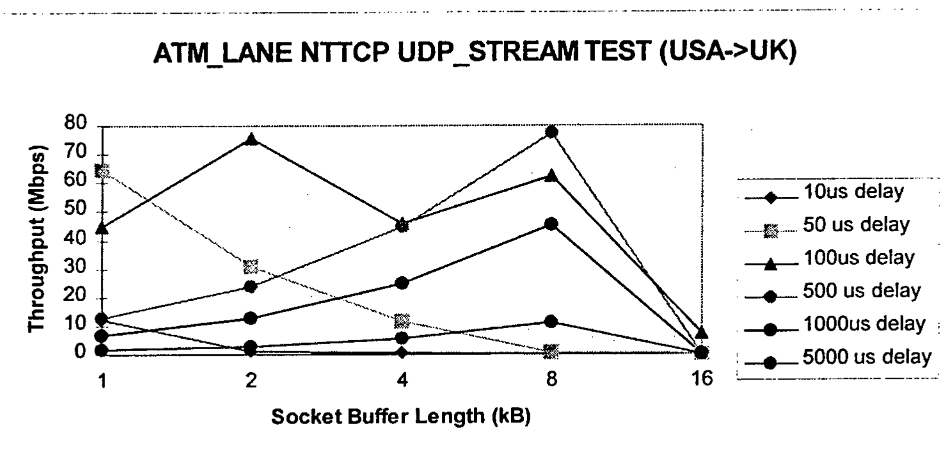


Figure 6.3.3-2(a): ATM LANE UDP Performance (by NTTCP)

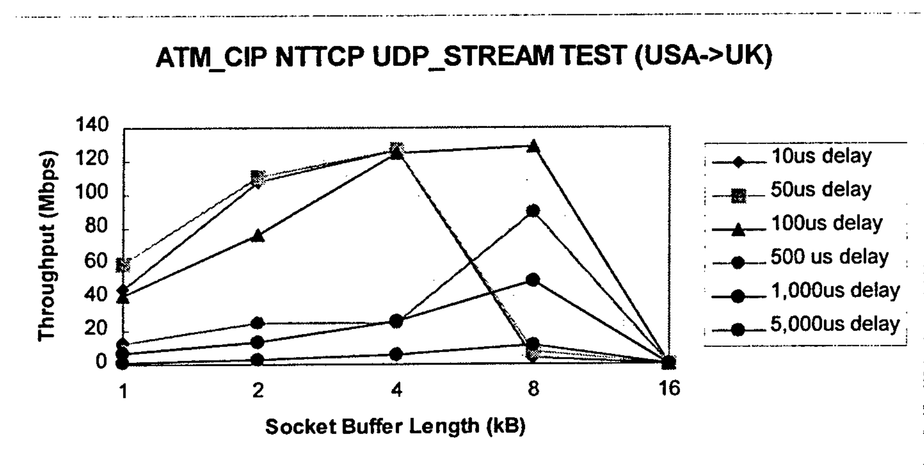


Figure 6.3.3-2(b): ATM CIP UDP Performance (by NTTCP)

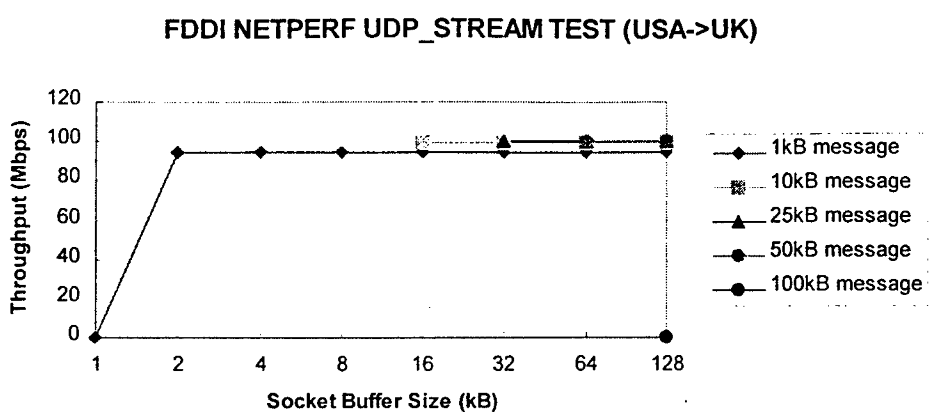


Figure 6.3.3-3(a): FDDI UDP Performance

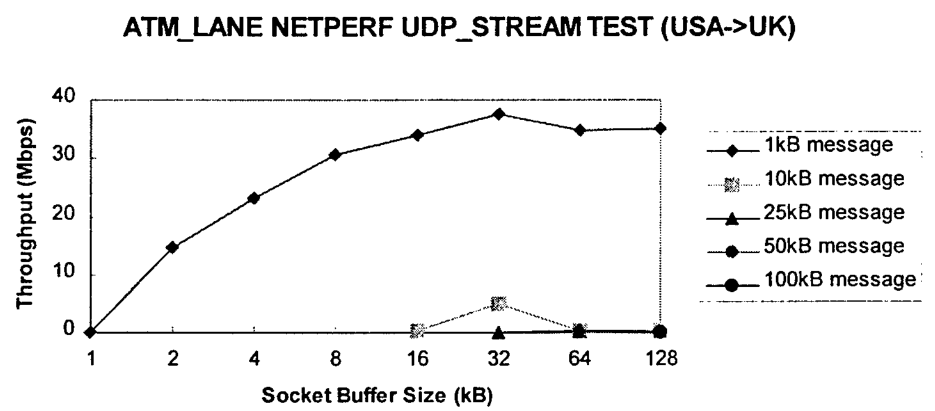


Figure 6.3.3-3(b): ATM LANE UDP Performance

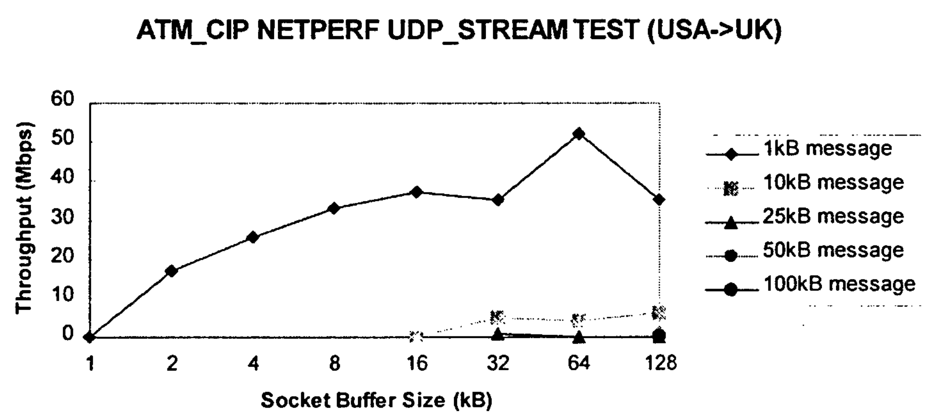


Figure 6.3.3-3(c): ATM CIP UDP Performance

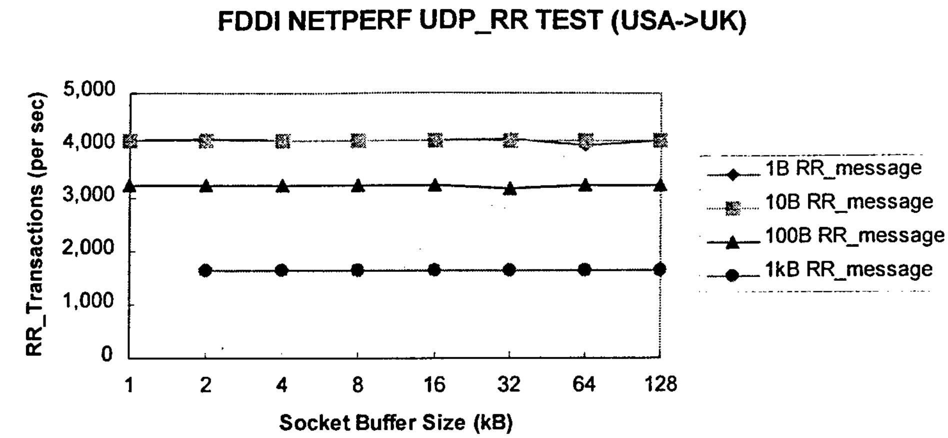


Figure 6.3.3-4(a): FDDI UDP Performance

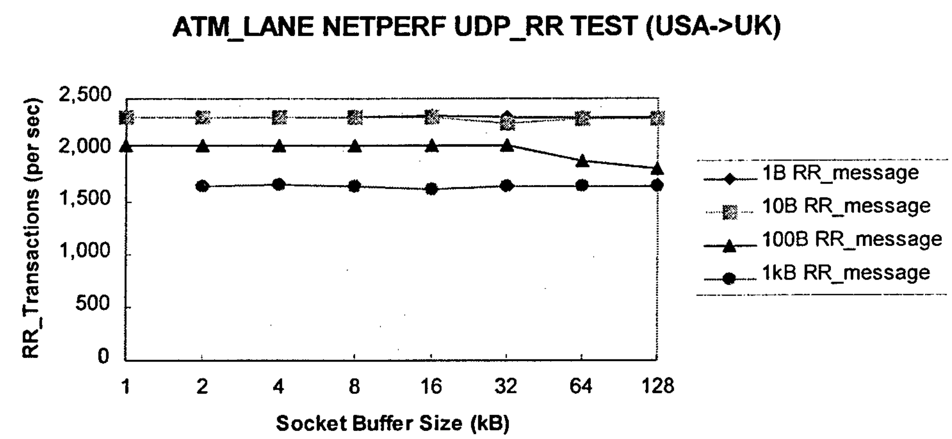


Figure 6.3.3-4(b): ATM LANE UDP Performance

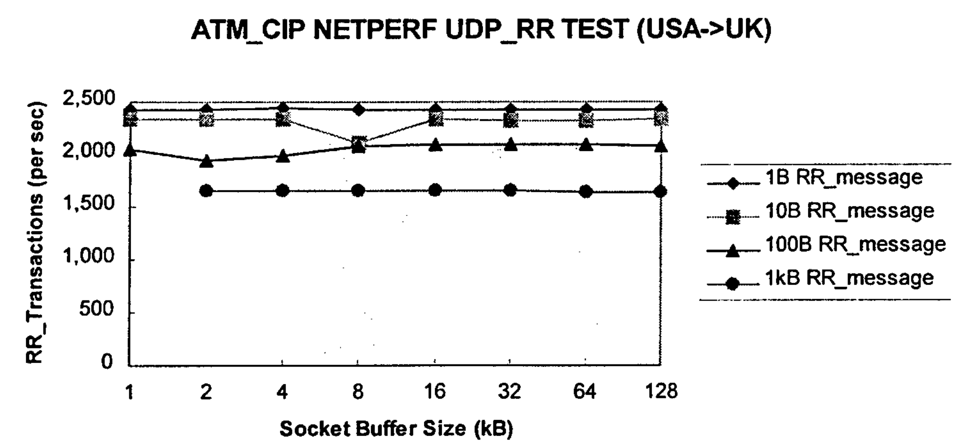


Figure 6.3.3-4(c): ATM CIP UDP Performance

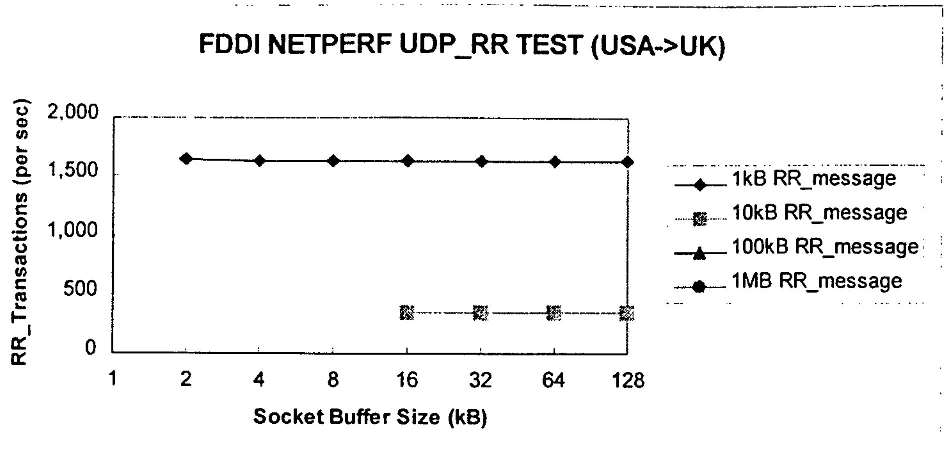


Figure 6.3.3-5(a): FDDI UDP Performance

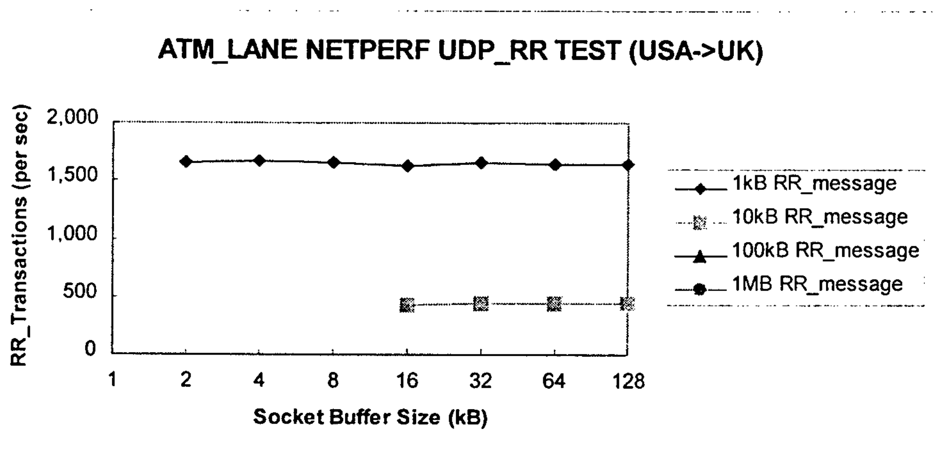


Figure 6.3.3-5(b): ATM LANE UDP Performance

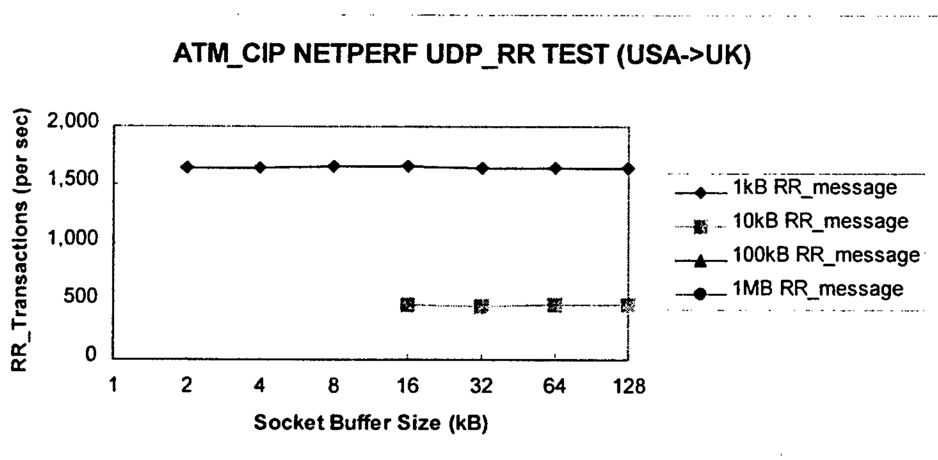


Figure 6.3.3-5(c): ATM CIP UDP Performance

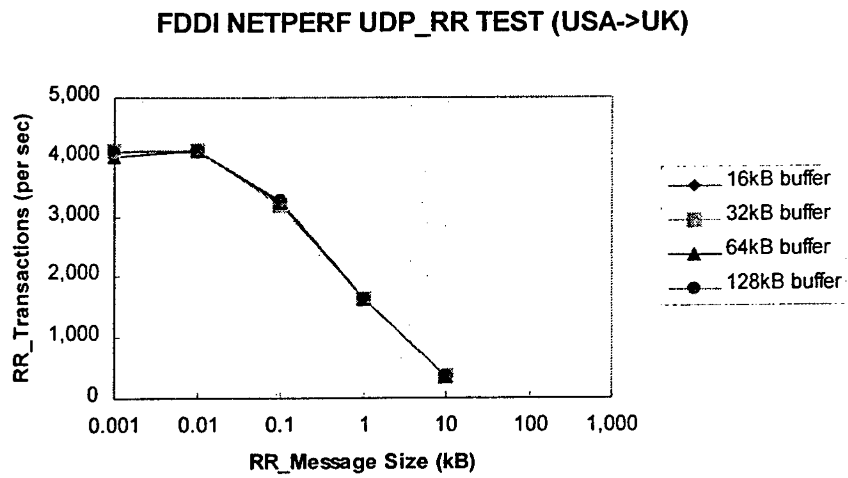


Figure 6.3.3-6(a): FDDI UDP Performance

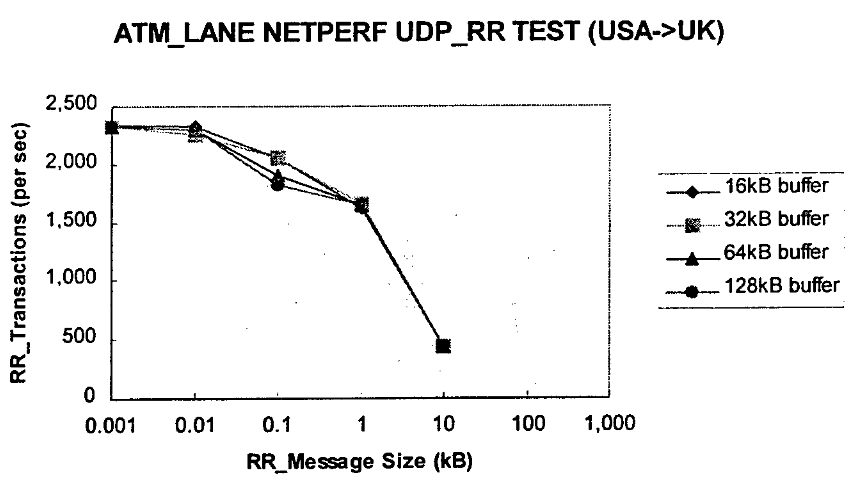


Figure 6.3.3-6(b): ATM LANE UDP Performance

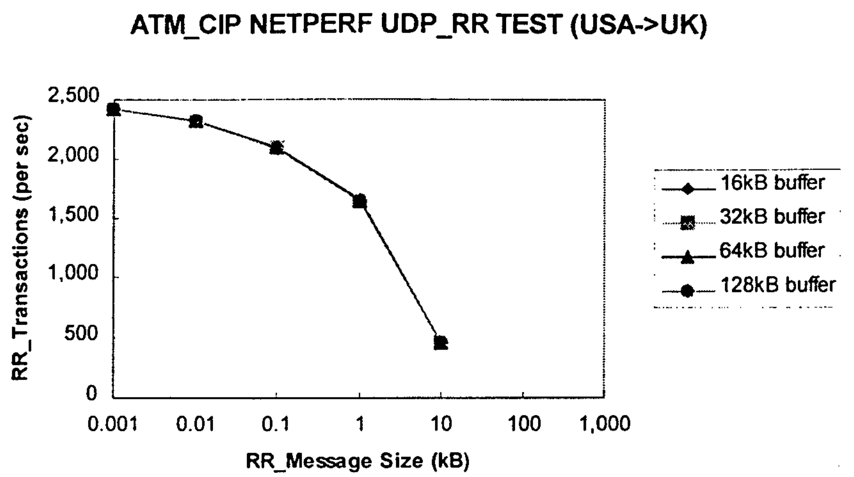


Figure 6.3.3-6(c): ATM CIP UDP Performance

6.3.4. Simultaneous TCP and UDP Performance Test

A. Objective:
This configuration is a superposition of the previous two configurations simultaneously demonstrating (1) multiple point-to-point TCP connections between a Mission Computer (MC) and four Display Consoles (DC), and (2) a single point-to-point and/or point-to-multipoint UDP communication stream from one MC to four DCs. The objective of this test is first to measure the throughput of multiple point-to-point TCP connections over each network implementation, in the presence of configuration (2), and second to measure the throughput of a single point-to-point and/or point-to-multipoint UDP distribution over each network implementation, in the presence of configuration (1).

B. Approach:
With the same approach as sections 6.3.2 and 6.3.3, the parameters were DC receive/transmit buffer size, MC transmit/receive buffer size, MC TCP transmit message size, and MC UDP transmit message size. Multiple TCP connections between the MC and DCs were established simultaneously with a single UDP distribution from the MC to the DCs, and corresponding throughputs were measured.

C. Test Items:

- Throughput at MC/DCs.

D. Test Procedure:

a) Use Netperf and/or NTTCP on MC (server) and DCs (client).
b) Vary the transmit buffer sizes on the MC and DCs.
c) Vary the receive buffer sizes on the MC and DCs.
d) Vary the transmit message sizes on the MC.
e) For each combination, observe and record throughput at the MC and DCs.
f) For receive/transmit socket buffer sizes of 1, 2, 4, 8, 16, 32, 64, and 128K bytes on the MC and DCs.
g) For MC transmit message sizes of 1, 10, 25, 50, 100, 500K, 1, 5, 10M bytes.
h) Measure the throughput with simultaneous P-P TCP and P-P and/or P-M UDP connections for each DC.

E. Expected Results:
The NTTCP and NETPERF do not allow for the simultaneous TCP and UDP test. One potential way was testing TCP performance while running UDP traffic on background, and vice versa. Figure 6.3.4-1(a), (b) show test examples of the FDDI network in the simultaneous TCP and UDP stream. Note that one type of traffic was handled first and the other traffic waited for its turn, so this might not be a true simultaneous test of TCP and UDP. Therefore, the truly simultaneous test of TCP and UDP was performed with an AWACS application program in Section 6.4.

Since a real AWACS application requires TCP unicast and/or UDP multicast, besides the separate TCP and UDP unicast tests, it would be interesting to test the performance of (1)

TCP or UDP multicast, (2) simultaneous TCP unicast and UDP unicast, and (3) simultaneous TCP unicast and UDP multicast. However, it should be noted that the UDP multicast and the simultaneous TCP and UDP multicast tests are not easily implemented with network benchmark tools. They are tested only by running actual AWACS application programs as described in the next section. The one way for us to closely simulate the scenarios above is by running multiple copies of netperf at the same time. Figures 6.3.4-1 and 6.3.4-2 show the example of TCP multicast test by sending a TCP_STREAM test message to all destinations (a.k.a, TCP-All) at the same time. The test script with multiple copies of netperf commands allows TCP and UDP streams to run at <u>*almost*</u> the same time. It is worthwhile to mention that these tests need more study to establish their validity of test method and results (Figures 6.3.4-1 and 6.3.4-2).

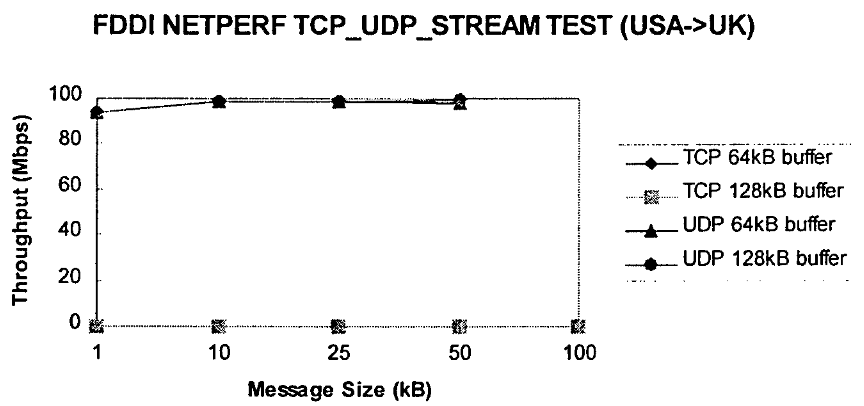


Figure 6.3.4-1(a): FDDI TCP and UDP Performance

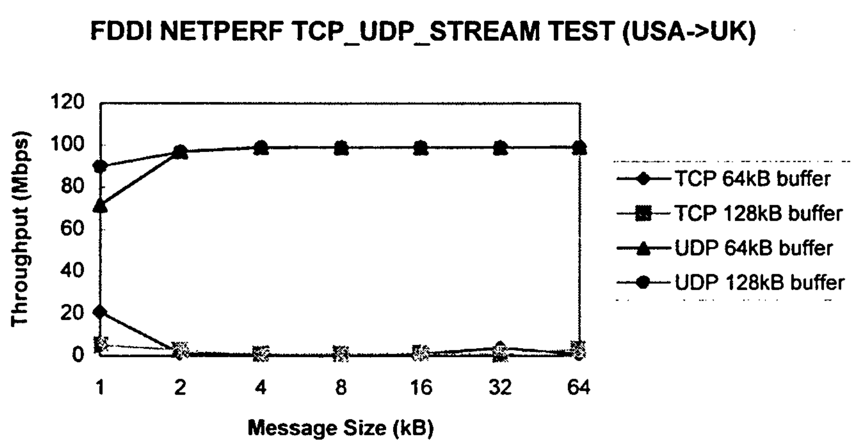


Figure 6.3.4-1(b): FDDI TCP and UDP Performance

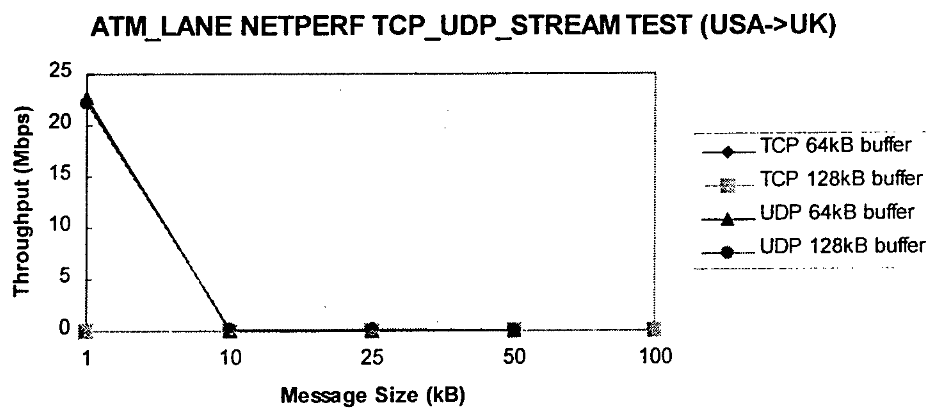


Figure 6.3.4-1(c): ATM LANE TCP and UDP Performance

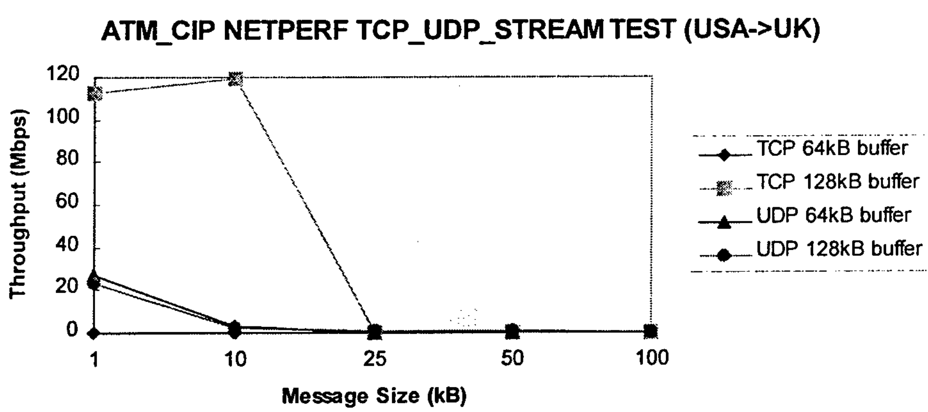


Figure 6.3.4-1(d): ATM CIP TCP and UDP Performance

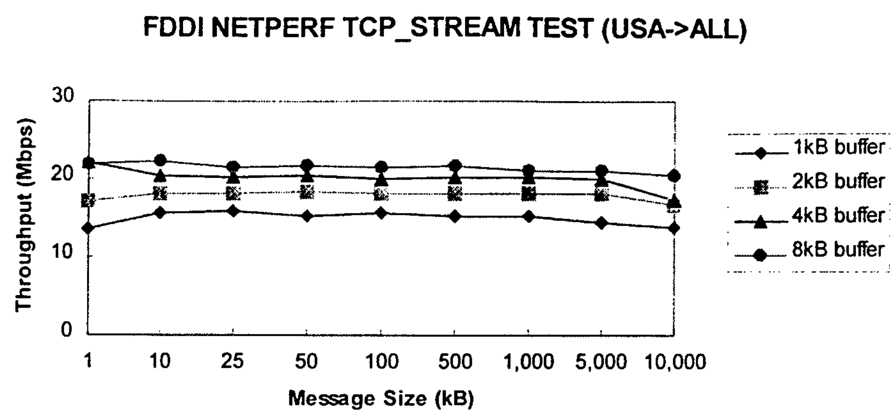


Figure 6.3.4-2(a): FDDI TCP Performance

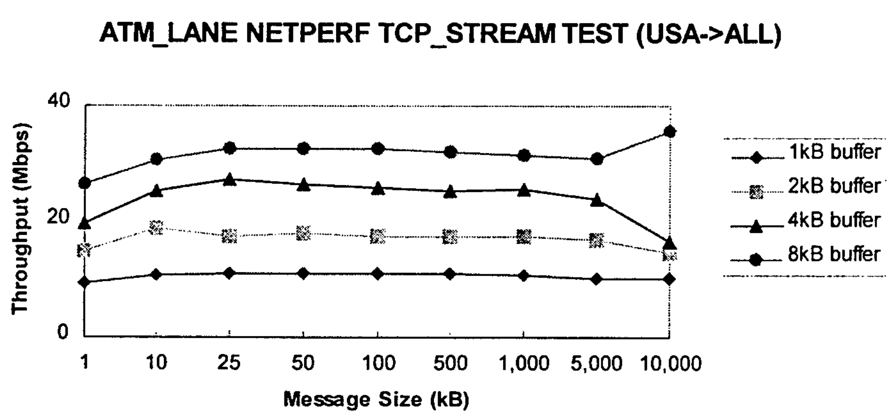


Figure 6.3.4-2(b): ATM LANE TCP Performance

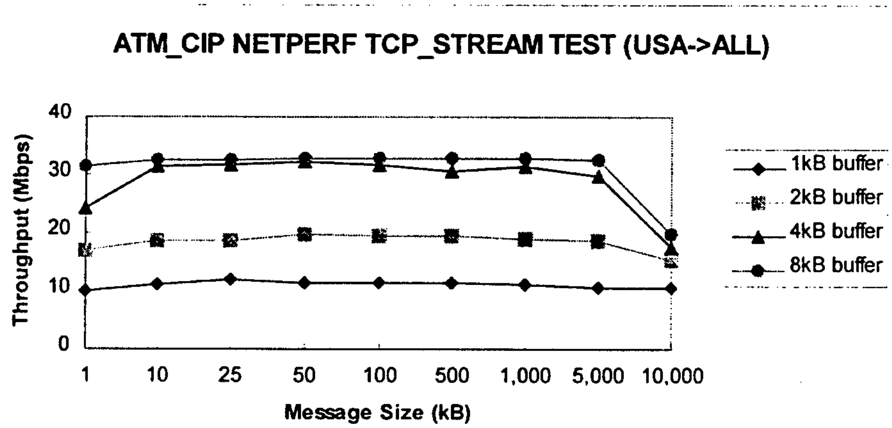


Figure 6.3.4-2(c): ATM CIP TCP Performance

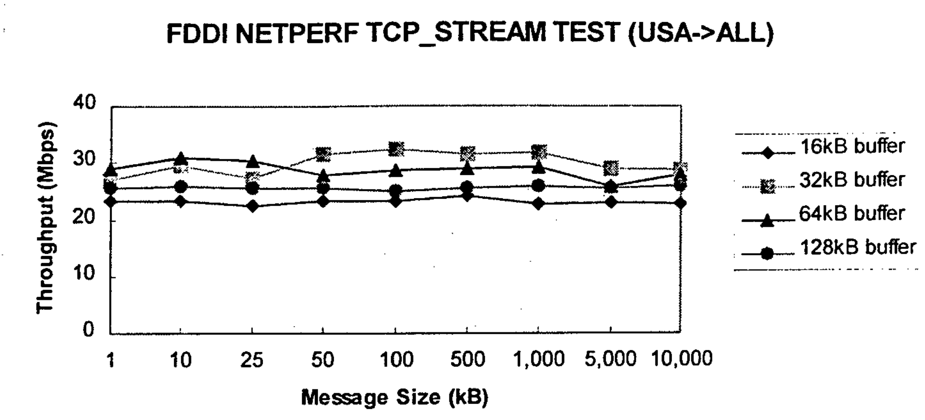


Figure 6.3.4-3(a): FDDI TCP Performance

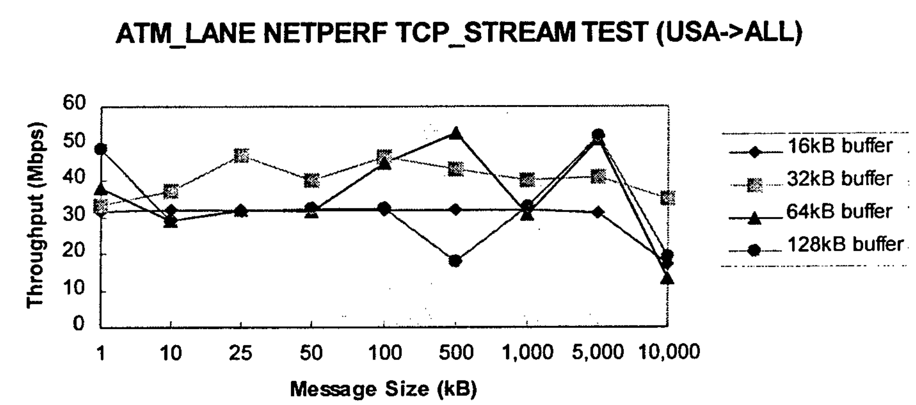


Figure 6.3.4-3(b): ATM LANE TCP Performance

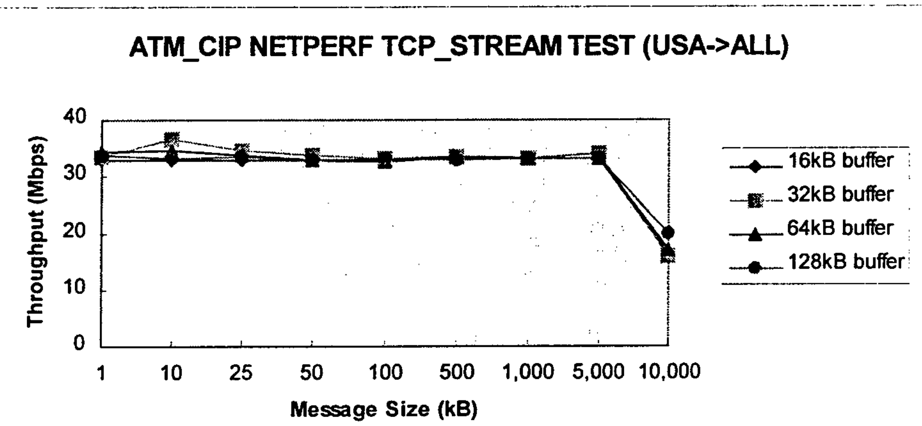


Figure 6.3.4-3(c): ATM CIP TCP Performance

6.4. ATM/FDDI Application Benchmark Test with AWACS Programs

The AWACS system loading can involve a large number of simulated targets, sensor returns (e.g., radar returns, IFF returns), and active tracks. The proper number of tracks and simulated targets allowed by the system may be generated. The simulated targets are used to perform an internal simulation of targets within the system. Sensor returns are then generated internally by the Mission Computer (MC) program applications and they are used to generate tracks. Once the number of simulated targets have been generated, automatic track initiation will be started and tracks will be generated off the simulated sensor returns. This information is continuously transmitted to the Display Console (DC) program and it can be displayed as requested.

6.4.1. TCP Performance Test

A. Objective:
To observe the qualitative TCP unicast performance of representative compilations of the Advanced AWACS application software running over each applicable network implementation: ATM Permanent Virtual Circuits (PVC), ATM LANE, and FDDI networks.

B. Approach:
For each network implementation (ATM PVC, ATM LANE, and FDDI), representative compilations of the AWACS application will be executed on the target platforms consisting of one Mission Computer (MC) and four Display Consoles (DC). A series of executables will be compiled, each with the capacity to handle a progressively larger number of targets (1000, 2000, 3000). This approach will exercise the network sufficiently to examine the effects of each network implementation on the actual performance of the system. The intent of this approach will be to determine the loading impact at which network functionality is degraded in an observable manner.

C. Test Items:

- Point-to-point TCP performance as a function of maximum number of targets: Performance of the actual TCP connections between the MC and the DCs will be evaluated as satisfactory or not-satisfactory based on observing the tabular display indicator Time. This indicator is updated at a 1- to 2- second rate and represents software watchdog timer activity operation to a 100-ms time resolution. Aberrations in the displayed time values are indicative of TCP connection problems.

- General network performance as a function of maximum number of targets: Certain communication network errors associated with software-detectable aberrations will cause the activation of a user-alert - indicative of the network communications problem.

D. Test Procedure:
Beginning with the executable compiled for the smallest number of targets and proceeding through progressively larger such executables, the representative AWACS application will be executed with appropriately sized scenarios. The application will be run on each network implementation and all network observables indicated above will be noted. Other means of automating the observation process may also be employed.

OSA AWACS application software was built for benchmark testing. This test software allows for varying the number of simulated targets (1,000, 2,000, 3,000) and socket buffer size (up to 1.5 MB). The network benchmark software tools (e.g., nttcp, netperf) were installed into all platforms (i.e., Alpha, Sparc, and Onyx workstations) of demonstration systems. With these network test software and application test software, we first performed the FDDI benchmarking, followed by ATM testing. We reconfigured all system components (AWACS, UAV, and fighter) by connecting to the FDDI and ATM networks for the network benchmark test.

The application performance test was performed with the Advanced AWACS Mission Computer Program (MCP) and Display Console Program (DCP). The C^4I platform system loading can be a large number of simulated targets, sensor returns (radar or IFF returns), and active tracks. The maximum number of over 1,000 tracks and simulated targets were generated. Sensor returns were then generated internally by the AWACS mission computer. Once the number of simulated targets have been generated, the automatic track initiation will be started and the tracks generated off the simulated sensor returns. This information is continuously transmitted to the AWACS Display Consoles to observe the simultaneous TCP unicast and UDP multicast performance of the Advanced AWACS application running over each network.

E. Expected Results:
Due to the worst-case scenario design of the Advanced AWACS system, whereby a large portion of the entire database is continuously updated, our observations are expected to be consistent with normal operation up to a critical network loading point, beyond which one or more of the aberrations listed above are expected to occur, manifested in a manner consistent with the observable as stated above.

Figures 6.4.1-1, -2, -3 show a summary of the Advanced AWACS application test with various track simulations that require TCP unicast transmission over each of three different network configurations. The AWACS application program was modified for this test so that the socket buffer size could be changed at run time. Test results showed that all networks had various problems associated with a mission computer program and/or database transmit problems below a buffer size of 32kB. The MCP problems include the occasional disconnect/reconnect, shutdown, or radar returns disappear of simulated target data. The database transmit problems involve various databases that do not get transmitted, i.e., either no target, point objects, or no tracks get updated. Above 64kB, the FDDI and ATM CIP showed normal operation, while ATM LANE also showed mostly normal with an occasional database transmit problem.

The files <osa_app_test.txt> contain observations related to running a modified OSA application test build over the FDDI, ATM LANE, or ATM CIP/PVC network.

NOTE: The OSA application is modified for this test so that the socket buffer size can be changed at run time. The OSA application has 40 socket buffers. In the OSA application, most socket buffers are set to a default size of 32*1024, while a few sockets handling larger amounts of data are set to 128*1024, and the sockets handling the database transfer are set to a function of the database size not exceeding 1400*1024. However, in this modified OSA application test build, all sockets are set to a single value of buffer size specified in the configuration file <./DATA/CONFIG_DATA/network_test.cfg>.

<u>CLOCK</u>: The number shows a maximum clock update time (on the display console tab) that was observed in seconds. Clock updates to the tab do not necessarily correspond to actual time.

<u>CRASH</u>: At least one of the Display Control Programs (DCP) is crashed or permanently disconnected from the Mission Computer Program (MCP) while running the OSA application test.

<u>DBASE XMIT</u>: The various databases do not get transmited; no target, point objects, or no tracks get updated.

<u>DISCONNECT</u>: The MCP occasionally disconnects and reconnects.

<u>DISAPPEAR</u>: The target data simulated radar returns disappear.

<u>HIGHLIGHT</u>: The Programmable Entry Panel (PEP) keys do not highlight properly.

<u>NORMAL</u>: The modified OSA application test build operates normally.

<u>PANIC</u>: The consoles running DCPs enter a panic mode and are automatically rebooted. One of the following error messages is displayed: (1) Panic (CPU 0): kernel memory fault; or (2) Panic (CPU 0): freeing free mbuf.

<u>SHUTDOWN</u>: The SHUTDOWN PEP key takes the MCP down, but not the DCPs.

Socket Buffer Size (Byte)	1,000 Tracks Simulation	2,000 Tracks Simulation	3,000 Tracks Simulation
1 k	CLOCK: 20 DBASE XMIT DISAPPEAR DISCONNECT HIGHLIGHT SHUTDOWN	CLOCK: 25 DBASE XMIT DISAPPEAR HIGHLIGHT SHUTDOWN	CLOCK: 30 DBASE XMIT DISAPPEAR HIGHLIGHT CRASH
2 k	CLOCK: 20 DBASE XMIT HIGHLIGHT SHUTDOWN	CLOCK: 15 DBASE XMIT HIGHLIGHT SHUTDOWN	CLOCK: 25 DBASE XMIT HIGHLIGHT SHUTDOWN
4 k	CLOCK: 5 DBASE XMIT HIGHLIGHT SHUTDOWN	CLOCK: 10 DBASE XMIT HIGHLIGHT SHUTDOWN	CLOCK: 5 DBASE XMIT HIGHLIGHT SHUTDOWN
8 k	CLOCK: 1 DBASE XMIT	CLOCK: 1 DBASE XMIT	CLOCK: 4 DBASE XMIT HIGHLIGHT
16 k	NORMAL: 3 DBASE XMIT (TORX / IT)	NORMAL	NORMAL: 3 DBASE XMIT (TORX / IT)
32 k	NORMAL: 3 DBASE XMIT (TORX / IT)	NORMAL	NORMAL
64 k	NORMAL	NORMAL	NORMAL
128 k	NORMAL	NORMAL	NORMAL
1500 k	NORMAL	NORMAL	NORMAL

Figure 6.4.1-1: AWACS Application TCP Unicast Test over FDDI

Socket Buffer Size (Byte)	**1,000 Tracks Simulation**	**2,000 Tracks Simulation**	**3,000 Tracks Simulation**
1 k	CLOCK: 35 DBASE XMIT DISAPPEAR DISCONNECT HIGHLIGHT SHUTDOWN	CLOCK: 20 DBASE XMIT DISAPPEAR DISCONNECT HIGHLIGHT SHUTDOWN	CLOCK: 25 DBASE XMIT DISAPPEAR DISCONNECT HIGHLIGHT SHUTDOWN
2 k	CLOCK: 6 DBASE XMIT DISAPPEAR HIGHLIGHT SHUTDOWN	CLOCK: 8 DBASE XMIT DISAPPEAR HIGHLIGHT SHUTDOWN	CLOCK: 4 DBASE XMIT DISAPPEAR HIGHLIGHT
4 k	CLOCK: 1 DBASE XMIT	NORMAL: 3 DBASE XMIT (FR)	CLOCK: 3 DBASE XMIT
8 k	NORMAL: 2 DBASE XMIT (UK, FR)	NORMAL: 3 DBASE XMIT (UK)	NORMAL: 3 DBASE XMIT (FR)
16 k	NORMAL: 2 DBASE XMIT (UK, FR)	NORMAL: 3 DBASE XMIT (FR)	NORMAL: 2 DBASE XMIT (UK, FR)
32 k	NORMAL: 3 DBASE XMIT (FR)	NORMAL: 3 DBASE XMIT (UK)	NORMAL: 2 DBASE XMIT (UK, FR)
64 k	NORMAL	NORMAL	NORMAL: 3 DBASE XMIT (FR)
128 k	NORMAL	NORMAL	NORMAL
1500 k	NORMAL	NORMAL	NORMAL

Figure 6.4.1-2: AWACS Application TCP Unicast Test over ATM LANE

Socket Buffer Size (Byte)	1,000 Tracks Simulation	2,000 Tracks Simulation	3,000 Tracks Simulation
1 k	CLOCK: 12 DBASE XMIT DISAPPEAR DISCONNECT HIGHLIGHT SHUTDOWN	CLOCK: 17 DBASE XMIT DISAPPEAR DISCONNECT HIGHLIGHT SHUTDOWN	CLOCK: 17 DBASE XMIT DISAPPEAR DISCONNECT HIGHLIGHT SHUTDOWN
2 k	CLOCK: 8 DBASE XMIT HIGHLIGHT SHUTDOWN	CLOCK: 7 DBASE XMIT HIGHLIGHT SHUTDOWN	CLOCK: 13 DBASE XMIT HIGHLIGHT SHUTDOWN
4 k	CLOCK: 6 DBASE XMIT HIGHLIGHT SHUTDOWN	CLOCK: 5 DBASE XMIT HIGHLIGHT SHUTDOWN	CLOCK: 7 DBASE XMIT HIGHLIGHT SHUTDOWN
8 k	CLOCK: 2 DBASE XMIT	CLOCK: 2 DBASE XMIT	CLOCK: 3 DBASE XMIT
16 k	NORMAL: 3 DBASE XMIT (UK)	NORMAL: 2 DBASE XMIT (UK, FR)	NORMAL: 3 DBASE XMIT (FR)
32 k	NORMAL: 2 DBASE XMIT (UK, FR)	NORMAL	NORMAL: 2 DBASE XMIT (UK, FR)
64 k	NORMAL	NORMAL	NORMAL
128 k	NORMAL	NORMAL	NORMAL
1500 k	NORMAL	NORMAL	NORMAL

Note: CIP* is a combination of "Classical IP" and "PVC multicast"

Figure 6.4.1-3: AWACS Application TCP Unicast Test over ATM CIP*

6.4.2. Simultaneous TCP and UDP Performance Test

A. Objective:
To observe qualitatively the simultaneous TCP and UDP performance of representative compilations of the Advanced AWACS application software running over each applicable network implementation: ATM Permanent Virtual Circuits (PVC), ATM LAN Emulation (LANE), and FDDI networks.

B. Approach:
For each network implementation (ATM PVC, ATM LANE, and FDDI), representative compilations of the AWACS application will be executed on the target platforms consisting of one Mission Computer (MC) and four Display Consoles (DC). A series of executables will be compiled, each with the capacity to handle a progressively larger number of targets (1000, 2000, 3000). This approach will exercise the network sufficiently to examine the effects of each network implementation on the actual performance of the system. The intent of this approach will be to determine the loading at which network functionality is degraded in an observable manner.

C. Test Items:

- Simultaneous TCP and UDP performance as a function of maximum number of targets: Performance of the actual UDP multicast distribution from the MC to the DCs will be evaluated as satisfactory or not-satisfactory based on observing the expected movement of the target on the display.

- General network performance as a function of maximum number of targets: Certain communication network errors associated with software-detectable aberrations will cause the activation of a user-alert - indicative of the network communications problem.

D. Test Procedure:
The application will be run on each network implementation and all network observables indicated above will be noted. Other means of automating the observation process may also be employed.

E. Expected Results:
Figure 6.4.2-1, -2, -3 show a summary of the Advanced AWACS application test with a 3,000-track-simulation that requires transmission of simultaneous TCP unicast and UDP multicast over each of three different network configurations. All networks had various problems associated with a mission computer program and/or database transmit problems below a buffer size of 32kB. The MCP problems include the occasional disconnect/reconnect, shutdown, or radar returns disappear of simulated target data. Above 64kB, the FDDI and ATM CIP showed normal operation, while ATM LANE also showed mostly normal with an occasional panic problem; the display consoles running AWACS programs occasionally entered a panic mode and automatically rebooted.

Socket Buffer Size (Byte)	1,000 Tracks Simulation	2,000 Tracks Simulation	3,000 Tracks Simulation
1 k	CLOCK: 60 DBASE XMIT DISAPPEAR DISCONNECT HIGHLIGHT SHUTDOWN	CLOCK: 90 DBASE XMIT DISAPPEAR DISCONNECT HIGHLIGHT SHUTDOWN	CLOCK: 120 DBASE XMIT DISAPPEAR DISCONNECT HIGHLIGHT SHUTDOWN
4 k	CLOCK: 6 DBASE XMIT DISAPPEAR HIGHLIGHT SHUTDOWN	CLOCK: 7 DBASE XMIT DISAPPEAR HIGHLIGHT SHUTDOWN	CLOCK: 8 DBASE XMIT DISAPPEAR HIGHLIGHT SHUTDOWN
8 k	CLOCK: 1 DBASE XMIT	CLOCK: 1 DBASE XMIT	CLOCK: 1 DBASE XMIT
16 k	CLOCK: 1 DBASE XMIT	CLOCK: 3 DBASE XMIT	CLOCK: 1 DBASE XMIT
32 k	CLOCK: 1 DBASE XMIT	CLOCK: 1 DBASE XMIT	CLOCK: 1 DBASE XMIT
64 k	NORMAL	NORMAL	NORMAL
128 k	NORMAL	NORMAL	NORMAL
1500 k	NORMAL	NORMAL	NORMAL

Figure 6.4.2-1: AWACS Application TCP and UDP Test over FDDI

Socket Buffer Size (Byte)	**1,000 Tracks Simulation**	**2,000 Tracks Simulation**	**3,000 Tracks Simulation**
1 k	CLOCK: 35 DBASE XMIT DISAPPEAR HIGHLIGHT SHUTDOWN	CLOCK: 30 DBASE XMIT DISAPPEAR HIGHLIGHT SHUTDOWN	CLOCK: 20 DBASE XMIT DISAPPEAR HIGHLIGHT SHUTDOWN
2 k	CLOCK: 8 DBASE XMIT DISAPPEAR HIGHLIGHT SHUTDOWN	CLOCK: 5 DBASE XMIT DISAPPEAR HIGHLIGHT SHUTDOWN	CLOCK: 6 DBASE XMIT DISAPPEAR HIGHLIGHT SHUTDOWN
4 k	CLOCK: 1 DBASE XMIT	CLOCK: 1 DBASE XMIT	CLOCK: 1 DBASE XMIT HIGHLIGHT
8 k	CLOCK: 1 DBASE XMIT	CLOCK: 1 DBASE XMIT	CLOCK: 1 DBASE XMIT CRASH: 1 (IT)
16 k	CLOCK: 1 DBASE XMIT	CLOCK: 1 DBASE XMIT	CLOCK: 1 DBASE XMIT
32 k	CLOCK: 1 DBASE XMIT	CLOCK: 1 DBASE XMIT	CLOCK: 1 DBASE XMIT
64 k	NORMAL	NORMAL	NORMAL PANIC: 1 (GR)
128 k	NORMAL	NORMAL	NORMAL PANIC: 1 (FR)
512 k	NORMAL PANIC: 1 (UK)	NORMAL PANIC: 3 (UK, FR, IT)	NORMAL PANIC: 3 (UK, FR, IT)
1000 k	NORMAL PANIC: 1 (UK)	NORMAL PANIC: 2 (FR, IT)	NORMAL PANIC: 2 (FR, GR)
1500 k	NORMAL PANIC: 2 (GR, IT)	NORMAL PANIC: 4	NORMAL PANIC: 4

Figure 6.4.2-2: AWACS Application TCP and UDP Test over ATM LANE

Socket Buffer Size (Byte)	1,000 Tracks Simulation	2,000 Tracks Simulation	3,000 Tracks Simulation
1 k	CLOCK: 25 DBASE XMIT DISAPPEAR DISCONNECT HIGHLIGHT SHUTDOWN	CLOCK: 25 DBASE XMIT DISAPPEAR DISCONNECT HIGHLIGHT SHUTDOWN	CLOCK: 30 DBASE XMIT DISAPPEAR DISCONNECT HIGHLIGHT SHUTDOWN
2 k	CLOCK: 7 DBASE XMIT HIGHLIGHT SHUTDOWN	CLOCK: 6 DBASE XMIT HIGHLIGHT SHUTDOWN	CLOCK: 12 DBASE XMIT HIGHLIGHT SHUTDOWN
4 k	CLOCK: 6 DBASE XMIT HIGHLIGHT SHUTDOWN	CLOCK: 6 DBASE XMIT HIGHLIGHT SHUTDOWN	CLOCK: 6 DBASE XMIT HIGHLIGHT SHUTDOWN
8 k	CLOCK: 2 DBASE XMIT	CLOCK: 2 DBASE XMIT	CLOCK: 2 DBASE XMIT
16 k	CLOCK: 2 DBASE XMIT	CLOCK: 2 DBASE XMIT	CLOCK: 2 DBASE XMIT
32 k	CLOCK: 2 DBASE XMIT	CLOCK: 2 DBASE XMIT	CLOCK: 2 DBASE XMIT
64 k	NORMAL	NORMAL	NORMAL
128 k	NORMAL	NORMAL	NORMAL
512 k	NORMAL	NORMAL	NORMAL
1000 k	NORMAL	NORMAL	NORMAL
1500 k	NORMAL	NORMAL	NORMAL

Note: CIP* is a combination of "Classical IP" and "PVC multicast"

Figure 6.4.2-3: AWACS Application TCP and UDP Test over ATM CIP*

7. ATM-BASED AWACS SYSTEM DEMONSTRATION (TASK 4)

The objective of the interim demonstration is to demonstrate the Advanced AWACS subsystem configured with an ATM backbone. In this task our intent is to demonstrate the same functionality based on ATM-based networks as is available in the current Advanced AWACS architecture based on Ethernet and FDDI networks. This interim demonstration involves a simulated AWACS. The demonstration uses actual flight software with internal simulations in such a manner that the designed-to limits of the system can be stressed. Over 1,000 targets will be simulated which, in turn, produce thousands of sensor returns from the simulated targets (e.g., radar, IFF, ESM) and over 1,000 system tracks - all of which are routed to all the consoles for display. This demonstration will verify that ATM is capable of handling the operational traffic.

Using the surveillance officer and weapons director, the advanced AWACS demonstration scenario includes the capabilities of various displays, targets/tracks and battlespace management, and Air Tasking Order (ATO) processing and data display.

1. ATM Network Demonstration.
   a) Describe ATM network configuration (ATM switch connection).
      1) LAN emulation configuration.
      2) Classical IP configuration.
      3) Multicast PVC configuration.
   b) Demonstrate ATM network configuration (ping, nttcp or netperf).
      1) LAN emulation configuration.
      2) Classical IP configuration.
      3) LANE multicast and PVC multicast in the nttcp UDP chatter mode.

2. Advanced AWACS Demonstration.
   a) Surveillance officer.
      1) Display a new SAM site.
      2) Set the ESM line of bearing for the new SAM.
      3) Look at a TACELINT MESSAGE.
      4) Identify the new SAM site as SA-10.
      5) Predict best intercept.
      6) Select the fighter to use against the SA-10.
   b) Weapons Director.
      1) Clear the predict lines.
      2) Commit the selected fighter to the SA-10.
      3) Check range/bearing of fighters to SAM sites.
      4) Within weapon range, drop range/bearing lines, and delete SAM sites from screen.
      5) Commit CAP fighter to one hostile fighter.
      6) Commit selected fighter to the other hostile fighter.
      7) Show approaches.

3. Interactive Future AWACS Demonstration.
   a) Displays demonstration.
      1) Situation displays: sensor data, area definition and control.
      2) Tabular displays.
      3) Points displays.
      4) Background maps displays.
      5) Missile and weapon sites displays.
      6) Latitude/Longitude grid displays.
      7) Range grid displays.
      8) AWACS Line-Of-Sight (LOS) displays.
      9) Range bearing and tactical range bearing lines.
      10) Amplification data hook (AMP hook) displays.
   b) Targets and tracks demonstration.
      1) Radar operation: pulse Doppler vs. beyond the horizon.
      2) Active track initiation and monitoring.
      3) Track management.
      4) Target simulation.
      5) Target motion, attributes, and interaction.
      6) Aircraft navigation.
   C) Battlespace management demonstration.
      1) Identification Friend or Foe (IFF) / radar - sectors and subsectors.
      2) Electronic Support Measure (ESM) simulation and control.
      3) Weapons control.
      4) Flight plan monitoring.
      5) Air Tasking Order (ATO) processing and data display.

4. Maximum Targets Demonstration of over 1,000.

8. INTEGRATED BATTLESPACE SIMULATION (TASK 5)

The objectives of this task were to integrate all subsystems into the final demonstration configuration, define a realistic demonstration scenario for C^4I specific applications, and demonstrate the "sensor-C4I-shooter" sequence in an integrated battlespace simulation environment. The final demonstration system consisted of an Advanced AWACS station (an OSA mission computer and four display consoles), a simulated UAV ground station (DEMPC mission planner and image analyzer), a remote advanced fighter station (display generator and cockpit display), and a remote computer image generator station. They were located at the Integrated Technology Development Laboratory (ITDL). A diagram of the final demonstration is shown in Figure 4.3-2.

The Integrated Battlespace Simulation (IBS) environment at the ITDL will provide simulated participants such as shooter, UAV, C^4I platform, or enemy threats, etc., and their connectivity for interaction between participants to specifically demonstrate and analyze intercommunications and data management with operators in the loop. The modular architecture of the environment will make it capable of supporting multiple players in joint warfare scenarios.

The entire off-board-sensor-to-shooter sequence will be modeled in the simulated battlespace environment that is designed to exercise the timeliness of receiving tactical information, including the response time of the operators. Each simulation node resides in separate laboratories that communicate over fiber cables. The sequence consists of video imagery from the sensor image collector simulation laboratory (UAV ground station) to the battle management station (C^4I platform) where it is processed and disseminated to the weapons platform aircraft displays (Shooter). The mission computer and display console workstations hosting the Open System Architecture (OSA) capability will represent the interaction of AWACS as a Hardware-In-The-Loop (HITL) system. An actual DEMPC mission planner and image analyzer will represent the interaction of the UAV. A SAR processor residing on an SGI Indigo-2 computer will provide the off-board sensing element for the UAV. One of the ITDL dome simulators will host the shooter aircraft (advanced fighter). Common databases will be used to develop correlated images for the out-of-cockpit visual system and the SAR processor. Other participants in the scenario will provide additional workload and data load functions.

For the actual demonstration, a simulated real-time Synthetic Aperture Radar (SAR) image will be used. The SAR image will be taken from the image generator's visual database. The video data will be captured and processed by the SGI Indigo-2 sensor (SAR) video processor and transmitted via an RS-170 video link to the image analysis display on the DEMPC ground station. Additional information will be added to the image which will then be transmitted via ATM to the OSA DEC Alpha AWACS operator's station. The resultant image will then be passed to the SGI Onyx cockpit display processor via an ATM link along with voice communications between the shooter and the C^4I platform. The information displayed in the shooter's cockpit will be used as targeting information.

8.1. AWACS-UAV-Fighter Subsystem Integration

The Integrated Battlespace Simulation (IBS) system implementation task puts all subsystems together into an IBS system for the final demonstration. Major subtasks include ATM link to fighter dome, fighter station interfaces to ATM and Distributed Interactive Simulation (DIS) networks, Toshiba big screen installation, UAV station (DEMPC) interfaces to ATM and DIS networks, SAR image processing and/or transfer to ATM, and IBS scenario demonstration.

ATM link to fighter station (F-2 dome): We evaluated a PCI-bus ATM adapter for the SGI Onyx-2 to support the ATM link to the advanced fighter dome and selected the FORE Systems' PCA-200EUX ATM adapter. The ATM adapter (PCIbus-based) was installed into the SGI Onyx-2 workstation and configured as a fighter platform using ATM LAN emulation and classical IP over ATM schemes. In parallel, the Mojo workstation (simulated fighter) was significantly improved, so that it now represents a simplified fighter station with a joy-stick controller. This mojo station can be used as a back-up advanced fighter in the integration and testing in case the fighter dome is not available.

Large Flat Panel Display (FPD) screen installation: We obtained the Toshiba driver required for the FPD screen and verified its operation. The required DEC Alpha Kernel was built with the new Toshiba driver. The new test driver was installed into the DEC Alpha 500 workstations and the functionality was fully tested.

AWACS OSA compiler upgrade: The AWACS OSA compiler has been upgraded from ADA-83 to ADA-95 in ITDL. This ADA-95 upgrade will provide the AWACS platform (mission computer) with enhanced operational capabilities. The ADA-95 also provides an additional capability of incorporating virtual reality networking. Since the single SGI Onyx-2 workstation (Osprey in F-2 dome) serves two functions (i.e., one as a fighter platform and another as a simulation manager station) there is a need for "virtual link" network technology. The "VR-Link" (by Mak Technologies, Inc.) is a line of software product that is used for the demonstration of distributed synthetic environments.

SAR image transfer to UAV-AWACS-fighter: The test files of SAR images (preprocessed image) was developed and kept on the UAV (DEMPC) platform. The SAR image file transmission was successfully tested from UAV (DEMPC) to the AWACS station (mission computer) over the ATM network. Subsequently, the SAR image file transmission was also tested from the UAV via the AWACS to the fighter station in the F-2 dome.

8.2. Integrated Battlespace Simulation

The battlespace simulation demonstration scenario is derived from the Joint Suppression of Enemy Air Defense (JSEAD) program. It involves a conflict between two regional powers that have evolved into an active combat situation. The allied forces are deployed in the area supporting a defensive coalition. The demonstration events occur during the early days of the conflict, and depict JSEAD activities leading to the achievement of air supremacy. Within this environment, enemy forces can generate counter-air actions (air-to-air, surface-to-air) and also be capable of conducting land, air and naval combat operations. The demonstration scenario covers the following major phases of activity:

(1) Allied air forces are conducting coordinated attacks against enemy air defense assets and associated command and control elements as the preliminary step toward achieving air superiority in theater.
(2) AWACS uses the off-board resource data as well as on-board sensors to detect and target threat emitters, and initiates strike operation with available air-ground assets.
(3) Advanced fighters engage threat emitter sites.
(4) AWACS coordinates follow-on activities against other enemy air defense assets (e.g., fighter aircraft).

For demonstration purposes, the scenario has been established in the Southwest CONtinental United States (CONUS) to take advantage of capabilities that exist in the ITDL (e.g., terrain databases). The scenario map shows the locations, flight paths, and relative geometry of participants.

A. Scenario Map:
A map of the demonstration scenario, Figure 8.2-1, shows nominal emitter locations for initial planning purposes. Orbits of AWACS and Combat Air Patrol (CAP) fighters are shown as ellipses on the map. Routes for ATO-designated missions/targets are shown as arrows representing axes of approach. Details for individual entities will be updated and refined as the scenario design is completed. The locations of several support assets, including ships, are also shown; however, these will not be represented as real-time simulation entities.

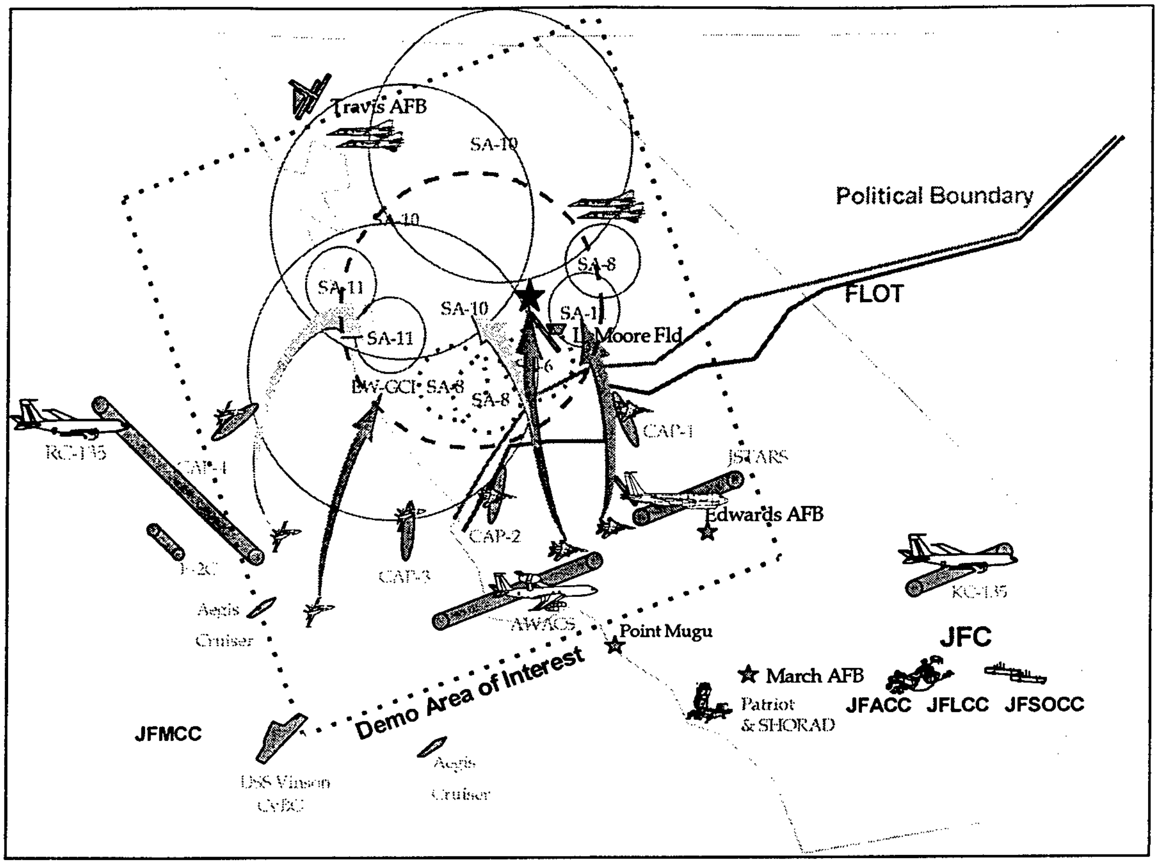


Figure 8.2-1: Integrated Battlespace Simulation Demonstration Scenario Map

B. Scenario Timeline:

The overall timeline for the Phase 4 scenario is shown in Figure 8.2-2. It shows the key participants and the major activities that occur within the demonstration. Prior to the start of the simulation, some Surface-to-Air Missile (SAM) threats have been suppressed during an initial wave of JSEAD strikes. Defensive fighters have been pushed up to counter any enemy retaliatory strikes, including cruise missile strikes launched from ground, surface, and air platforms.

At the time of simulation start (t=to), the AWACS has been on station for several hours. The AWACS has an established air picture that shows the fighters (tracks with ID), a special point for the air defense unit, a KC-135 tanker orbiting to the theater (optional) and ingress fighters on ATO-directed JSEAD missions. The major events that occur over time in the scenario are as follows.

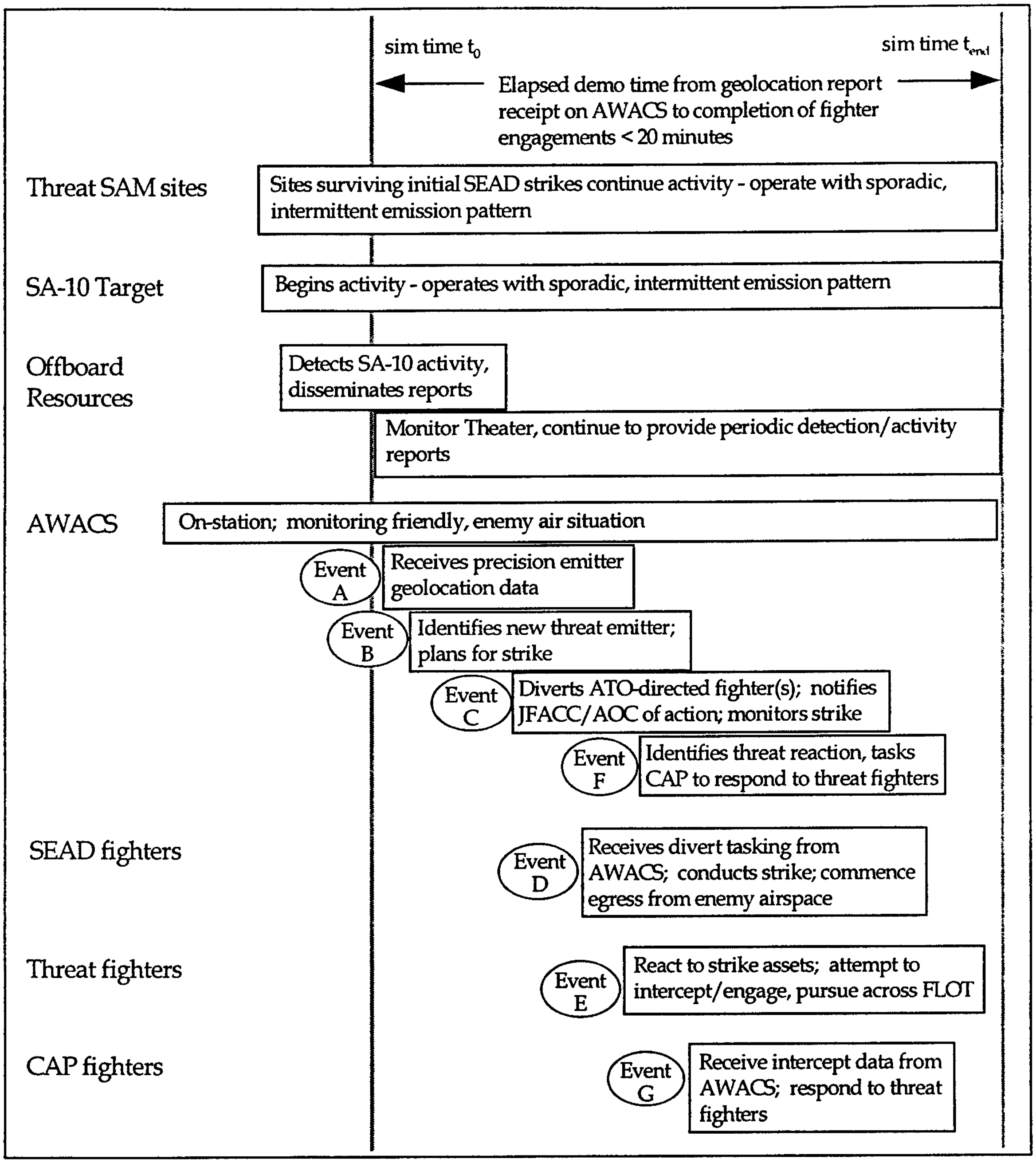


Figure 8.2-2: Integrated Battlespace Simulation Demonstration Scenario Timeline

Start of Scenario:
The enemy threat SAM sites that has survived initial JSEAD strikes continues activity.

Event 1: Fighter positioned about hundred miles from targets.
Event 2: SA-10 SAM target begins operation with sporadic, intermittent emission pattern.
Event 3: AWACS identifies new threat emitter, retasks airborne UAV, and plans for strike.
Event 4: AWACS identifies threat emitter and diverts Air Tasking Order (ATO)-directed fighter.
Event 5: AWACS notifies Joint Force Air Component Commander (JFACC) of action and monitors strike.
Event 6: Ground UAV controller uplinks SAR image of SAM enemy missile site to AWACS.
Event 7: The fighter receives divert tasking and SAR image of target from AWACS, conducts strike, and commences egress from enemy airspace.

End of Scenario:
AWACS detects enemy fighters reacting to strike.

9. AWACS NETWORK ARCHITECTURE TRADE STUDY (TASK 6)

A trade study of the on-board networks within the existing AWACS programs was performed. This trade study also includes the off-board network; the survey and future works on wireless ATM technologies – wireless satellite, wireless terrestrial, and wireless mobile ATM.

9.1. ATM Alternatives

The major criteria for the selection of network technology involve performance factors such as achievable throughput and delay, operational features, product availability, compatibility with higher layer protocols, upgradability, and cost and maintainability. In this section, the ATM alternative network technologies are described. These include mainly Fibre Channel, Gigabit Ethernet, and Fast Ethernet.

9.1.1. Fibre Channel Network

Fiber Channel is a network type whose main market niche has been in the high-speed transfer of data from disks to a processor. For such an application, Fiber Channel has demonstrated speeds on the order of 800 Mb/s or 100 MB/s. This is many times faster than ultra wide SCSI that is rated at 40 MB/s. Besides speed, another advantage of Fiber Channel is that the cable length is not as restrictive as SCSI (comparing with ultra SCSI cable lengths of less than 1.5 m). The main features of the Fibre Channel network are summarized as follows:

- ANSI X3.230 Standard mainly for channel operation up to 1.062 Gbps.
- High-speed data communications connections: channel and network.
- High performance point-to-point serial data channel.
  - 133 Mbps to 1.062 Gbps per direction.
  - 2.12 Gbps, 4.24 Gbps specified in FC-PH-2, 3.
- 5-layer Protocol Stack (Figure 9.1.1).
  - FC-0: Physical interface and media .
  - FC-1: Transmission protocol.
  - FC-2: Signaling protocol.
  - FC-3: Common services.
  - FC-4: Upper Layer Protocols (ULP) mapping.
- Support multiple existing protocol interfaces.
  - Channel: SCSI, HPPI, Intelligent Peripheral Interface (IPI), and Single Byte Command Code Set (SBCCS).
  - Network: IEEE 802.2 (LLC), IP, ATM AAL-5, Link Encapsulation (FC-LE).

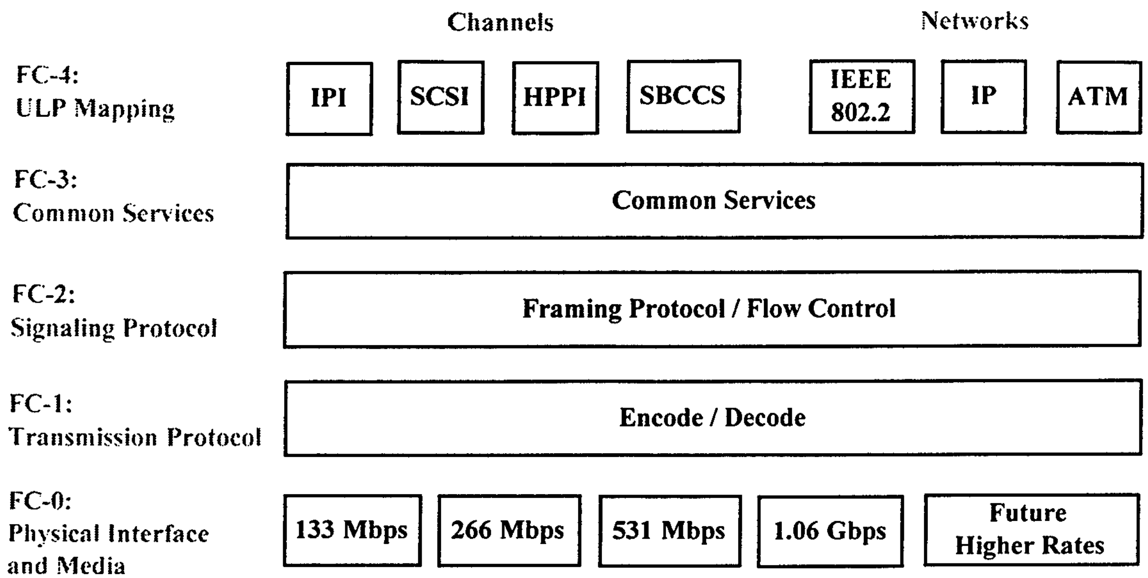


Figure 9.1.1: Fibre Channel Protocol Stacks

Advantages of Fibre Channel:

- Currently only technology with physical layer standard at gigabit speed; 133 Mbps to 1.062 Gbps per direction.
- Support both channel and network connections; mainly for high-speed data transport channel between processors and peripherals.
- Support multiple existing protocol interfaces; SCSI, HPPI, IPI, SBCCS, IEEE 802.2 (LLC), IP, ATM AAL-5, Link Encapsulation (FC-LE).
- Scalable connections; 16 million nodes on a single fabric (vs. 16 nodes in SCSI).

Disadvantages of Fibre Channel:

- Product availability.
- Product interoperability.
- Potential concern about throughput performance.

9.1.2. Gigabit Ethernet Network

Gigabit Ethernet preserves the fundamental concepts of standard Ethernet framing. It complies with the IEEE 802.3 standard for frame format and minimum and maximum frame size. However, the physical layer is different. It provides 1 Gbps bandwidth for campus networks as well as the simplicity of Ethernet at lower cost than many other technologies of comparable speed. It will offer a natural upgrade path for current Ethernet installations, leveraging existing end stations, management tools and training.

Gigabit Ethernet, like Fast Ethernet (in section 9.1.3), borrows an established physical layer standard from another technology. While Fast Ethernet has adopted a version of the FDDI physical layer standard, Gigabit Ethernet adopted a modified version of the ANSI X3T11 Fibre Channel physical layer standard (FC-0). Note that Fibre Channel is currently the only technology that supports gigabit speeds and it currently supports rates up to 4.268 Gbps. Gigabit Ethernet employs the same Carrier Sense Multiple Access with Collision Detection (CSMA/CD) protocol, same frame format and same frame size as its predecessors.

- IEEE 802.3z Standard for Ethernet operation at 1 Gbps.
- Support from Gigabit Ethernet Alliance (GEA); 80+ member companies.
- Preserve the fundamental concepts of standard Ethernet.
  - Ethernet framing.
  - Frame format, maximum and minimum frame size.
- Physical layer standard (Figure 9.1.2).
  - Adopt ANSI X3T11 Fibre Channel physical layer (FC-0) standard because only FC currently supports gigabit speeds (up to 4.268 Gbps).
  - Adopt FC's encode/decode layer (FC-1); 8B/10B coding technique.
- Support both half-duplex and full-duplex operation.
  - Gigabit Ethernet is most effective in the full-duplex, point-to-point mode where full bandwidth is dedicated between two points.
  - Switch has an option of half- or full-duplex on a port-by-port basis; allow for migration from shared to point-to-point, full-duplex segments.
- Optional flow-control mechanism is being defined under IEEE 802.3x.

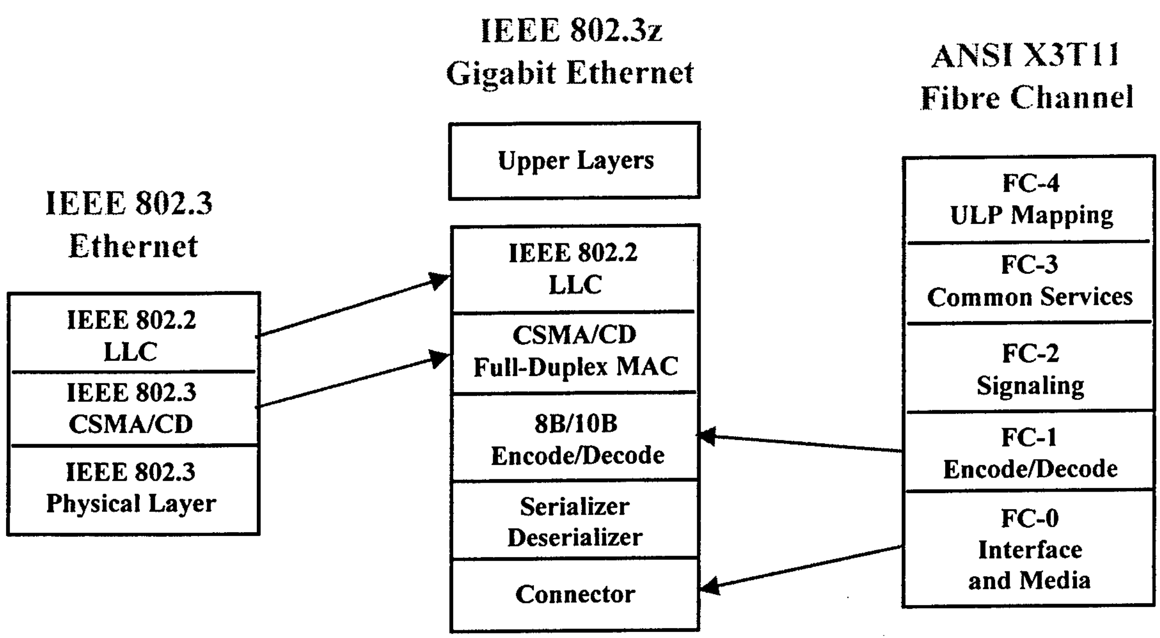


Figure 9.1.2: Gigabit Ethernet Protocol Stacks

Gigabit Ethernet Operation: Full-Duplex

- Use IEEE 802.3x full-duplex specification.
- Ideal for backbones, high-speed server or router links.
- Point-to-point connections only; not for shared-port connections, such as repeater of hub port; CSMA/CD is not required and disabled.
- Use IEEE 802.3x frame-based flow control; similar to XON/XOFF.

Gigabit Ethernet Operation: Half-Duplex

- Ideal for shared multistation LANs; two or more end users share a single port.
- Use standard Ethernet CSMA/CD access method.
- Gigabit Ethernet performance is degraded.
- Sensitive to segment length due to the use of CSMA/CD protocol.
- Standard slot time for Ethernet frames is too short to run a 100m cable when passing 64-Byte frame at gigabit speeds; timing is extended with no frame size change to guarantee 512-Byte slot time using "Carrier Extension."
- IEEE 802.3 specification requires 500m over multi-mode fiber at 1.0 Gbps; 500m (MMF), 3km (SMF), 25m (STP Coax), future 100m (UTP Cat 5).
- Gigabit Ethernet is limited to one repeater per segment (e.g., 2 for Fast Ethernet).

Advantages of Gigabit Ethernet:

- Use fundamental Ethernet concepts: Ethernet is the mainstream network.
- Support same frame format and size as Ethernet.
- Support existing network operating systems, network management, and applications; standard Ethernet CSMA/CD protocol.
- Potential for interoperability and backward compatibility.
- Potential for low-cost products.
- Potential for large, stable Ethernet vendors support.
- Potential for low risk and existing investment preservation.

Disadvantages of Gigabit Ethernet:

- Gigabit Ethernet products just beginning to be available.
- Gigabit Ethernet is not fully standardized.

9.1.3. Fast Ethernet Network

Fast Ethernet (IEEE 802.3u) is a faster version of Ethernet operating at 100 Mbps. Fast Ethernet maintains the concept of the IEEE 802.3 protocol and increases the throughput tenfold by speeding up the MAC. The physical layer signaling definition for Fast Ethernet is based on the FDDI standard. Fast Ethernet requires either a hub or a switch if any more than two devices are to be interconnected. Fast Ethernet can operate with either Category 5 twisted pair wire or optical fiber.

Current technology is such that the network interface cards that allow a device to communicate over Ethernet are implemented with auto-sense ASICs. It operates at either 10 Mbps or 100 Mbps depending on the connection made. In this manner, a hub or switch can have different speed devices connected to it. In the case of hubs, if a device communicates at only 10 Mbps then the device it communicates with must also be at 10 Mbps for that communication only. In the case of switches, normally a port transmits at its maximum speed of 100 Mbps even though the data are sent to the destination port at a slower speed of 10 Mbps. The Fast Ethernet speed of 100 Mbps is a half-duplex speed, and the full-duplex speed would be 200 Mbps per port.

A concern about Fast Ethernet technology relates to LAN topology considerations and the possible need to rewire perhaps a portion of the enterprise. The 10Base-T supports a diameter (the distance between farthest nodes) of 2.5 km. By contrast, in a single segment, the 100Base-T has a maximum collision domain, including repeaters, of only 205 m (half-duplex operation, balanced copper links, and no margin). Another concern relates to the fact that the specification sets a two-hub/repeater maximum (with an inter-repeater distance not to exceed 5 m) for latency reasons. Repeaters are permitted within a single collision domain to provide the maximum path length. The two-repeater limit implies a single-level hub structure, and since Fast Ethernet hubs on the market support 24 ports per hub, this results in a network with at most 48 stations. However, new

repeater chips under development will facilitate the hubs supporting 100 Fast Ethernet ports per hub. These hubs can then be connected to form a two-hub network of approximately 200 nodes.

9.2. Architecture Choice of Existing AWACS Programs

Existing AWACS programs have selected various network architectures tailored for their own requirements and applications. These include ATM, FDDI, Fast Ethernet, Gigabit Ethernet, and Fibre Channel. The network selection for existing programs is as follows:

1. Advanced AWACS OSA program:
   - Computer and display consoles: high-end workstation.
   - Network: ATM, Ethernet (Redundant).
2. US AWACS Extend Sentry Step 1 program:
   - Computer and display consoles: CC-2E , WSC/SDC.
   - Network: Fibre Channel.
3. NATO Midterm program:
   - Computer and display consoles: high-end workstation.
   - Network: Gigabit Ethernet.
4. EFX98 program:
   - Computer and display consoles: high-end workstation.
   - Network: ATM, Ethernet (Redundant).
5. Wedgetail program:
   - Computer and display consoles: high-end workstation.
   - Network: Fast Ethernet.
6. NIMROD program:
   - Computer and display consoles: high-end workstation.
   - Network: Fast Ethernet.

9.2.1. US Advanced AWACS Open Systems Architecture

Boeing is currently developing implementations of mission avionics for future advanced C^4I aircraft, including future Advanced AWACS. Advanced AWACS open systems architecture (OSA) program is an example. The Advanced AWACS OSA program has chosen the FDDI and redundant Ethernet as the mission computing LAN. Boeing has a prototype AWACS implementation in the laboratory, based on the Boeing-developed OSA design approach. This prototype has been developed in conjunction with U.S. Air Force AWACS personnel and is based on COTS technology. Figure 9.2.1 shows the OSA design for the current Advanced AWACS. Communications between the mission computer and display consoles are accomplished over the separate Ethernet and FDDI networks. A future AWACS will require advanced mission avionics architecture to meet the increased information processing requirements of future missions.

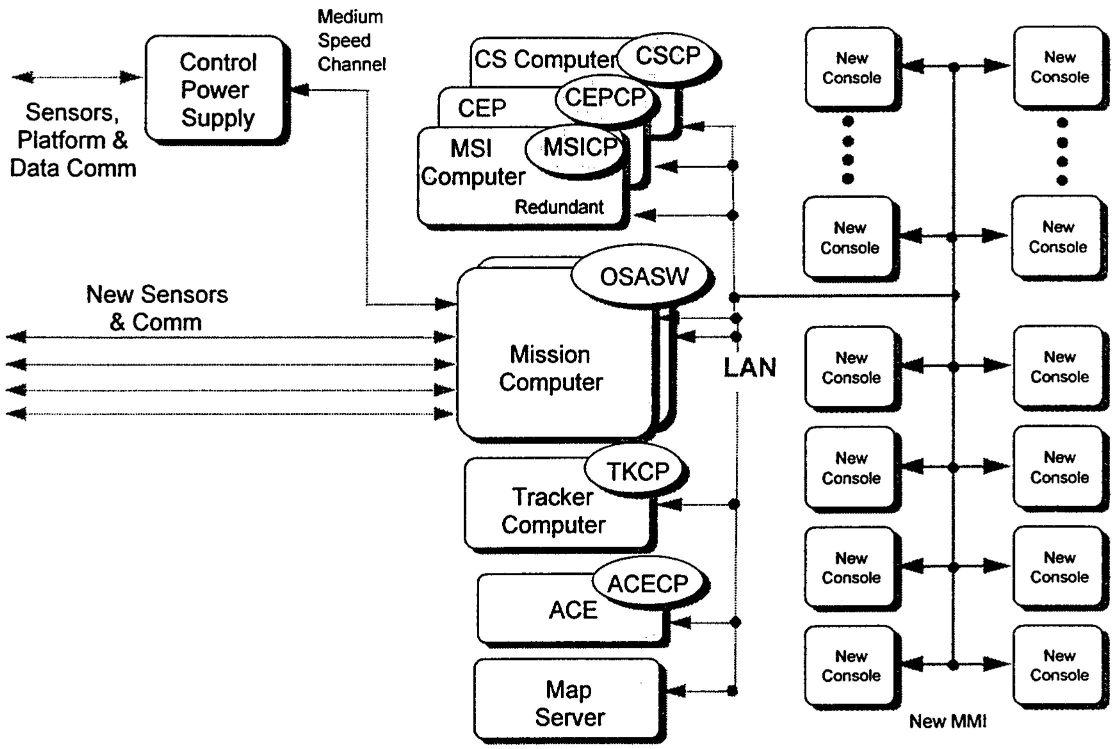


Figure 9.2.1: Open System Architecture for Advanced AWACS

Boeing is developing a COTS-based OSA display and control system to enable the AWACS to add new functions needed for future missions such as theater air (missile) defense, on-board and off-board multi-sensor integration, and theater battle management (e.g., JACE, air-to-ground mission support, dynamic ATO). Key hardware features of the OSA display and control system include:

a. Lightweight composite structure.
b. Open architecture (VME DEC Alpha-based solution).
c. Simplified Human-Computer Interface (HCI).
d. Large CRT (1024 x 1280 pixel resolution).
e. Trackball/mouse and QWERTY keyboard.
f. Function keypad.
g. Floppy disk for mission data.
h. CD ROM for tech orders, etc.
i. Retractable keyboard/keypad.
j. Designed to replace E-3 Situation Display Console (SDC).
k. Withstand 16g crash loads.
l. Growth margin.

Key features of the simplified human-computer interface include:

a. X Windows, MOTIF, OPENGL displays.
b. Display designed to minimize operator fatigue during long missions.
c. Video/SAR imagery in tactical displays.
d. Reduced operator workload.
e. Multiple tabular displays, tactical displays.
f. Supports multiple environments.
g. Raster and elevation maps.
h. Map overlaid with video.
I. Large color display.
j. Detailed map and weather displays.

9.2.2. US AWACS Extend Sentry Step-1 Architecture

The U.S. AWACS Extend Sentry program has chosen the Fibre Channel as the mission computing LAN as opposed to Fast Ethernet, Gigabit Ethernet, and ATM. Fibre Channel is ANSI-X3.230 Standard mainly for channel operation up to 1.062 Gbps. Fiber Channel is designed to be able to handle multiple types of data and protocols and its main market niche has been in the high-speed transfer of data from disk farms to a processor.

The main features of Fibre Channel technology are as follows:

- Currently, the only technology with a physical standard at a gigabit speed of 133 Mbps to 1.062 Gbps per direction
- Support both channel and network connections, mainly for high-speed data transport channel between processors and peripherals.
- Support multiple existing protocol interfaces.
- Scalable connections up to 16 million nodes on a single fabric.

The baseline configuration for U.S. AWACS Extend Sentry program is as follows:

- Ancor Fibre Channel switch as the baseline configuration.
- Systran Fibre Channel NICs and driver SW installed on the CDC Equipment.
- New NIC & Driver for DASA to be developed.
- Fiber optic cables to all devices - SC connectors on NICs and switch.

Although there were some concerns on the product availability, product interoperability, and throughput performance, Boeing had eventually resolved all these potential concerns. In addition, Boeing successfully developed a ruggedized switch design for the airplane environment to pass strict qualification testing. Figure 9.2.2 shows a diagram of US AWACS Extend Sentry Step-1 network architecture.

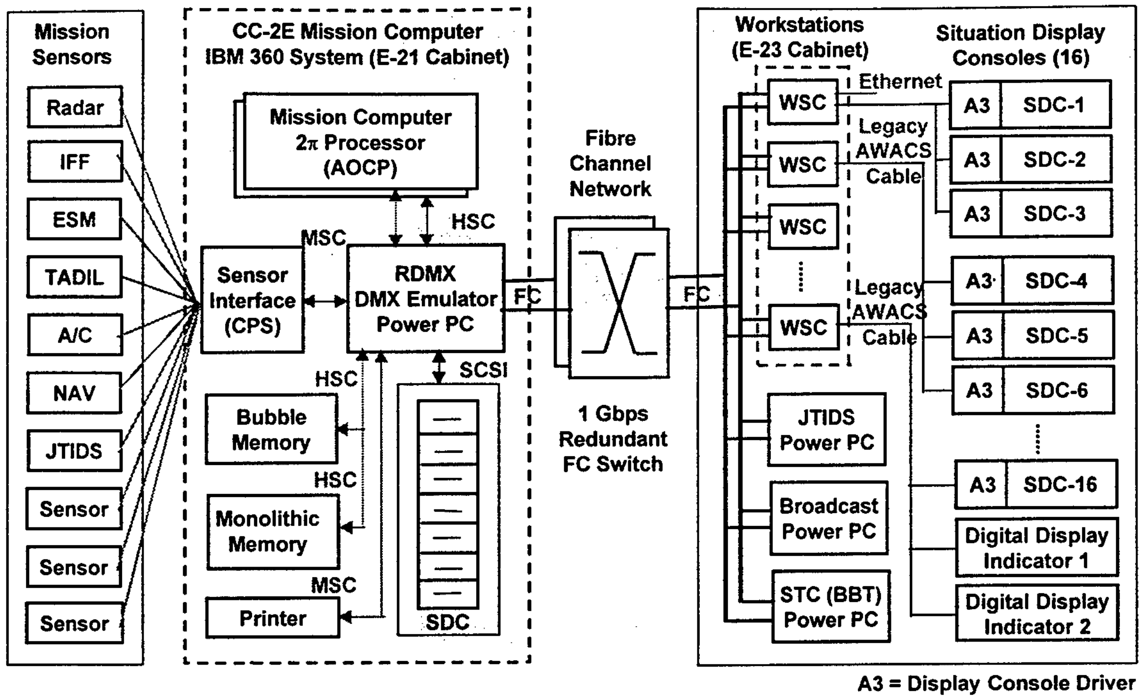


Figure 9.2.2: US AWACS Extend Sentry Step-1 Network Architecture

9.2.3. US Expeditionary Force Experiment AWACS Architecture

The 1998 Expeditionary Force Experiment (EFX98) demonstration involves data/video broadcasting from the ground station to multiple mobile platforms via a relaying satellite. The ground-to-air data rate is 1.544 Mbps via a relaying Ku-band satellite and the air-to-ground transmission date rate is 4.8 kbps via UHF satellite. The Yurie Systems' LDR-50 ATM Access Concentrator was used for the ATM WAN switch and an IBM 8260 Multiprotocol N-way Switch was used for the ATM LAN switch. The end systems were SUN Ultrasparc II-xi workstations running Solaris 2.5.1 and Pentium II-400 PCs running NT 4.0. Figures 9.2.3-1 and 9.2.3-2 show the network architecture of EOC and JFACC aircraft, respectively. The AWACS aircraft of the EFX98 demonstration deploys the US AWACS Extend Sentry Step-1 network architecture that uses a Fibre Channel LAN switch. As shown in Figure 9.2.3-3, there is a need for a gateway to convert between ATM (also Ethernet in EFX98) and Fibre Channel protocols. The Multi-Switching Service (MSS) router module of an IBM 8260 Multiprotocol N-way Switch performs this function.

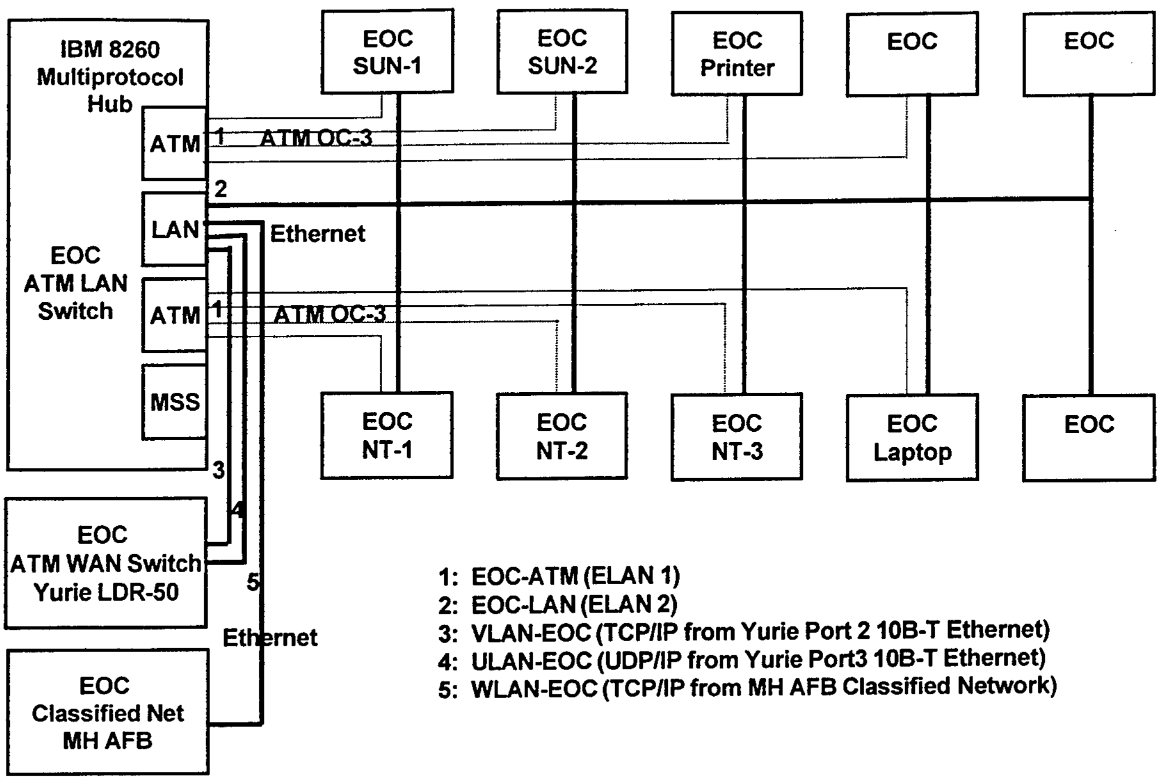


Figure 9.2.3-1: EOC Aircraft Architecture for EFX98 Demonstration

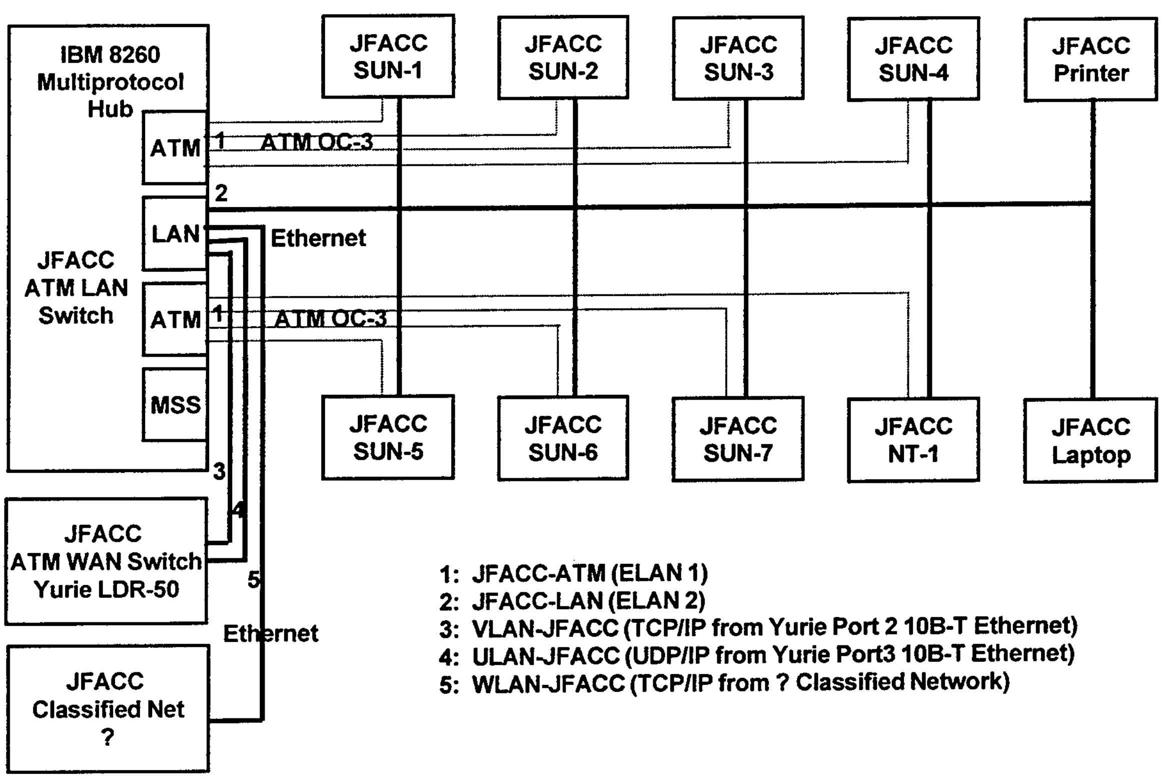


Figure 9.2.3-2: JFACC Aircraft Architecture for EFX98 Demonstration

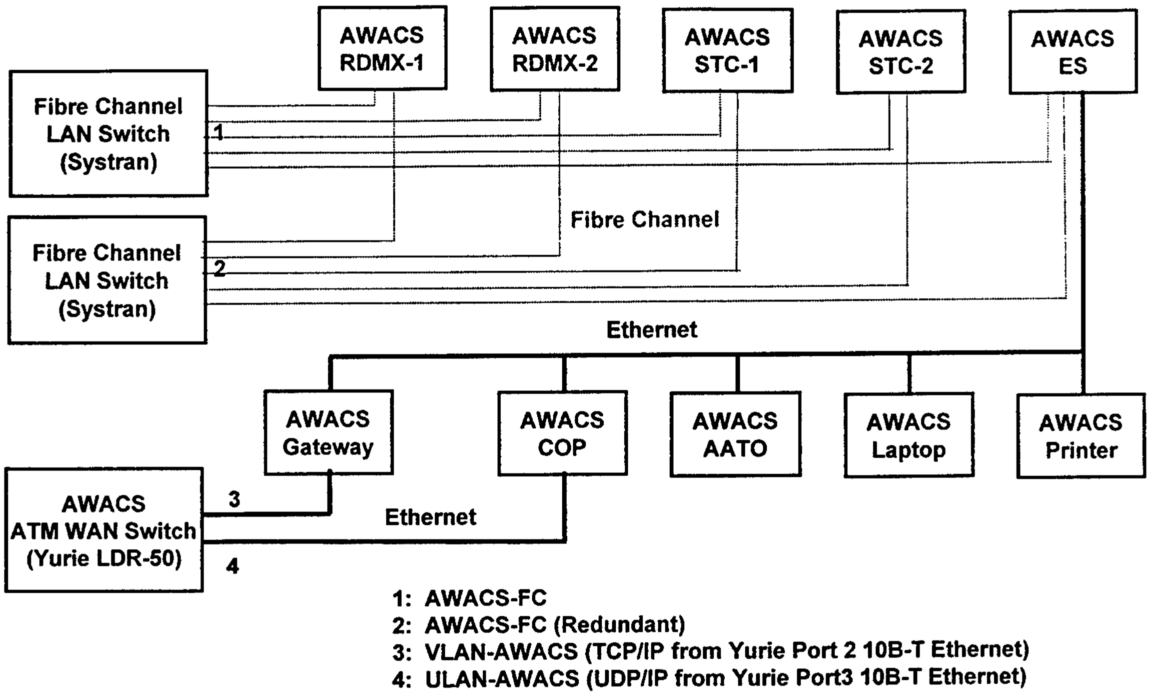


Figure 9.2.3-3: AWACS Aircraft Architecture for EFX98 Demonstration

9.2.4. NATO AWACS Midterm Architecture

NATO AWACS program has chosen the Gigabit Ethernet (Figure 9.2.4) as the mission computing LAN as opposed to Fast Ethernet, ATM, and Fiber Channel. Gigabit Ethernet is a faster version of Fast Ethernet, operating at 1 Gbps, and operates both over copper wires for short distances and optical fiber for longer distances. The Gigabit Ethernet standard is complete and the switch products become available.

The use of a LAN has a primary purpose to provide an efficient flow of data between AWACS Mission Computer (AMC) and other units. Many factors were considered for this choice including product maturity, market position, product suppliers, product performance, and the ability of products to work in the NATO system. Risk of required modification of COTS equipment and/or software for the proper functionality was also considered. The important selection criteria are:

- Achievable bandwidth.
- Broadcast and multicast capability: Mission Computer (MC) software uses multicast when transferring track data to the consoles.
- Availability of COTS hardware and software.
- Compatibility with TCP/IP and ORBIX.
- Operational reliability and fault tolerance.

- Production and maintenance costs.
- Scalability and upgradability.
- CPU-to-CPU latency and jitter.

There is a great difference between minimum and maximum CPU-to-CPU latency. In the case of minimum latency, all the candidates have latencies under 20 microseconds, which is considered trivial as a discriminator for a program. The maximum latency is dependent on heavily loaded network conditions where many ports are trying to output on the same port. The protocols that have the smallest cell or that can operate at gigabit speeds will have the smaller latencies. If we assume a 1500-Byte packet (e.g., Ethernet), the worstcase latency is estimated for 1 ms.

The required bandwidth estimate for the NATO Midterm Program is total raw data traffic of 92 Mbps. This includes 25 Mbps for T&C results and checkpoint; 22 Mbps per SDC for live mode displays, tracks, sensors, maps, and documents; 33 Mbps for X-checkpoint; 11 Mbps for normal and replay recording; and 1 Mbps for printers. Thus, the total throughput of 200 Mbps is required with 50% margin of error and 70% efficiency. Gigabit Ethernet provides the best overall performance/cost ratio and therefore is the best choice for the NATO Midterm program.

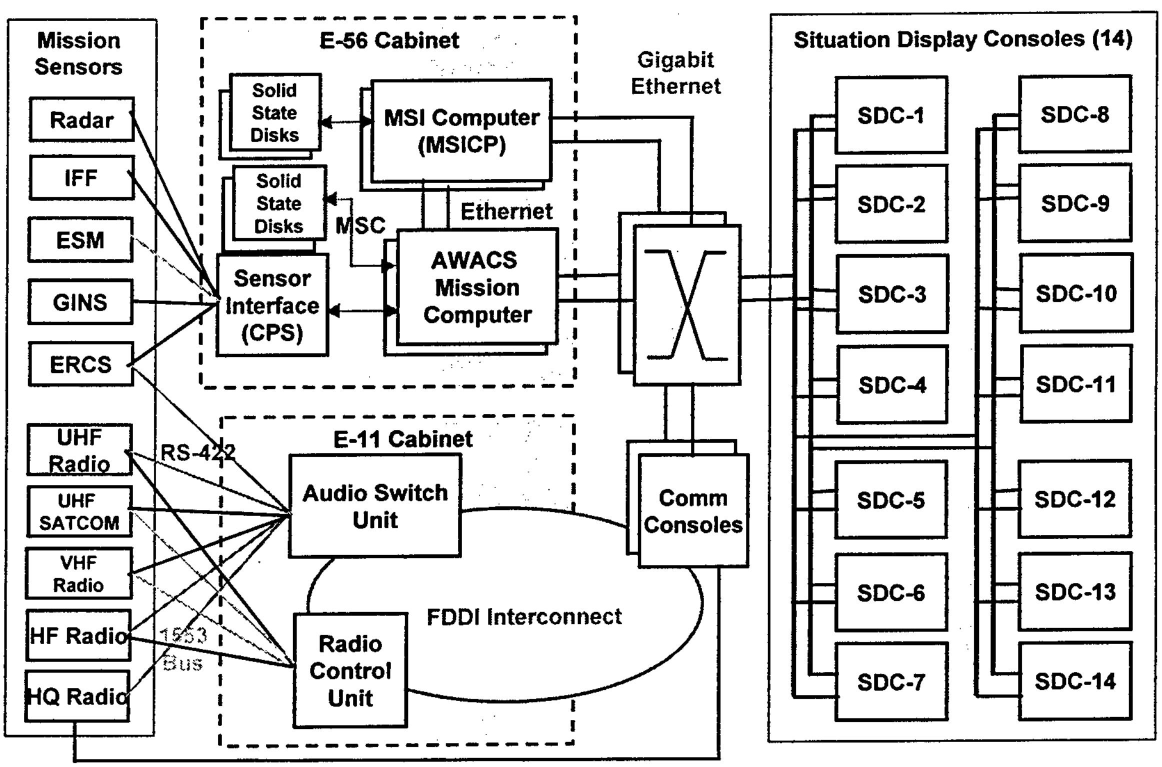


Figure 9.2.4: NATO AWACS Midterm Network Architecture

9.2.5. Australia AWACS Wedgetail Architecture

The baseline architecture of the Wedgetail mission system was based on the ATM LAN network (Figure 9.2.5). Recent changes in requirements of the baseline mission system removed a need of digitized audio transport over LAN and assigned it to a separate set of hardware items called the ICS. Since there is no requirement for continuous digitized audio or video on the Wedgetail LAN the guaranteed bandwidth is no longer an issue. Thus, there is a need to determine whether or not ATM would still provide the best Wedgetail solution.

The major traffic patterns are as follows:

- 10 Mbps for data processing that sends data to all consoles.
- 4 Mbps for centralized map server.
- 4 Mbps for sensor data and other types of data.
- 8 Mbps for data processing that sends checkpoint data.
- 4 Mbps for Radar, ESM, and EWSP.
- 4 Mbps for data output communication links.
- 3 Mbps for ICS audio record output.
- 1 Mbps for data processing to CEC.

The data processing LAN input and output is by far the highest data traffic at 6 Mbps (10 Mbps with CEC option) and 18 Mbps, respectively. It is proposed to have two LAN switches with a separate port from the data processing CPU to each switch.

In recommending a specific LAN type and hardware for the Wedgetail mission system, the following important selection criteria were considered in order of priority:

- Throughput.
- Compatibility with higher level protocols.
- Deployment history for Boeing programs.
- Ruggedization.
- Reliability.
- Upgradability.
- Availability.
- Cost.
- Weight.
- Latency.
- Multimedia capability.

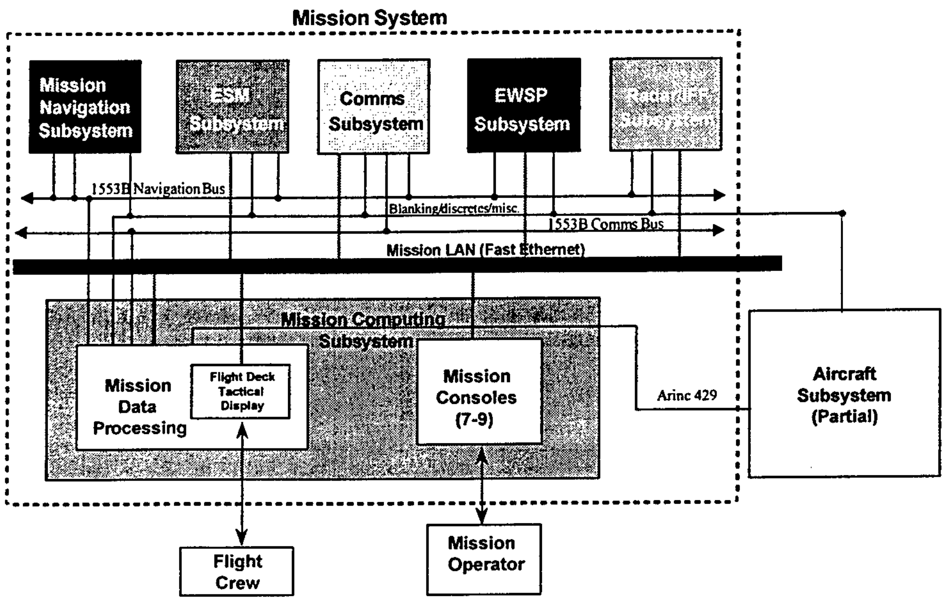


Figure 9.2.5: Wedgetail AWACS Mission System Network Architecture

9.2.6. British NIMROD Architecture

The basic TCS system has dual Input/Output Processors (IOP) mission computers and up to 8 workstations. These are interconnected using 100Base-T (IEEE 802.3u) with two switching hubs and also have redundant interconnects. The rest of the system consists of several sensors (e.g., radar, ESM, EO, acoustics). These sensors are connected to the IOPs by MIL-STD-1553 for the most part, so that the LAN can be used mainly for the central computing and displays.

A. FDDI-Based Design:
The baseline TCS computer bus architecture is shown in Figure 9.2.6-1. This configuration includes an FDDI bus (100 Mbps) for data between workstations and IOPs, and an internal 10Base-2 Ethernet bus (10 Mbps) that interconnects the workstations and IOPs, as well as the printers and acoustic video converter (that captures acoustic video and converts it to Ethernet data for the printers). A second Ethernet bus provides connectivity to elements external to the TCS (acoustic system, ESM, and DASS).

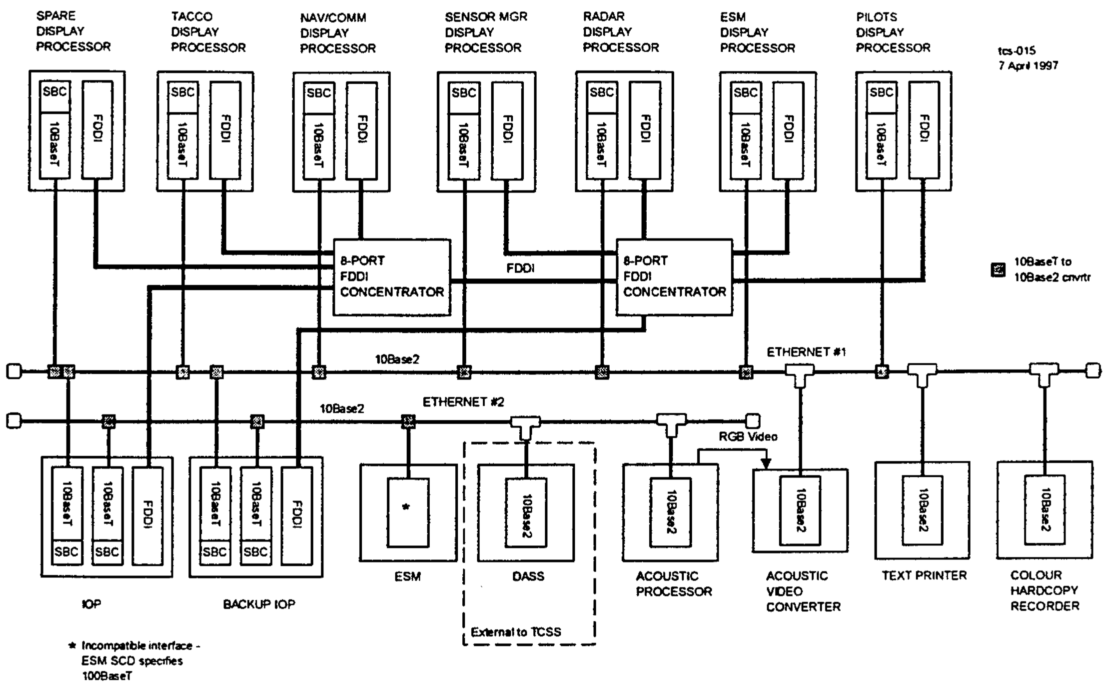


Figure 9.2.6-1: FDDI-Based TCS Computer Data Bus Architecture

Basic FDDI architecture involves dual counter-rotating rings to achieve fault recovery from a failed station. The difficulty with this arrangement is maintaining the network if two or more non-contiguous stations are not operational (for example, not powered up). In the baseline design, this situation is avoided by using concentrators, which perform the function of inserting or removing individual stations from the network. An alternative is the use of optical bypass relay at each station; however, it introduces optical power loss and probably decreases system reliability. Since the concentrators provide the fault recovery, stations are connected using the Single Attachment Station (SAS) configuration. Two interconnected concentrators are used, which provides a partial measure of redundancy. If either concentrator fails, the remaining unit interconnects a portion of the workstations to an IOP. Note that the current ESM SCD specifies a Fast Ethernet interface, which is not supported in the baseline.

B. Fast Ethernet-Based Design:
Replacement of FDDI with 100Base-T Fast Ethernet would involve replacement of FDDI concentrators with Ethernet hubs, and replacement of the FDDI VME cards with Fast Ethernet cards (now available in PCI mezzanine modules). An alternative architecture based on Fast Ethernet is given in Figure 9.2.6-2. Both FDDI and 10Base-2 Ethernet bus #1 are replaced with 100Base-TX (Fast Ethernet). The 10Base-2 Ethernet bus #2 is retained, though the connectivity is altered.

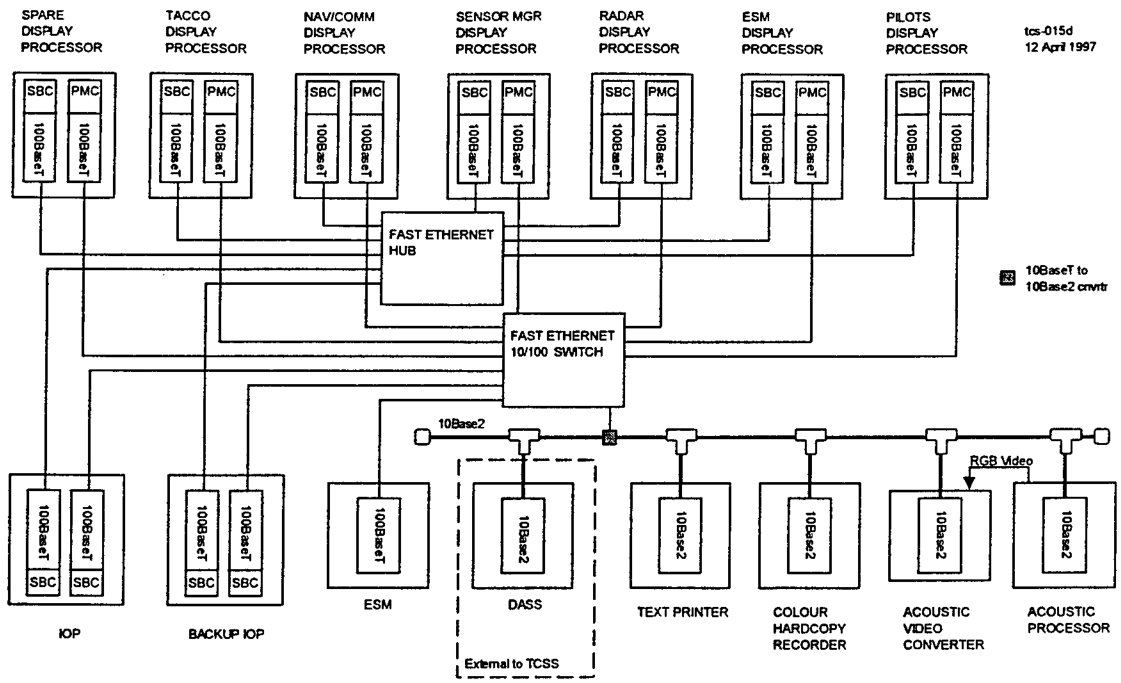


Figure 9.2.6-2: Alternative Fast Ethernet-Based Architecture

Not all stations on the bus can be converted to Fast Ethernet. DASS provides only a 10Base-T Ethernet interface. Neither offers Fast Ethernet as a current interface option. To serve the DMC text printer and the hard copy color recorder, a 10Base-T Ethernet is retained in the architecture. Two uncoupled Ethernet hubs are used, maintaining a degree of bus independence (and potential redundancy). One hub is a simple shared Ethernet device and another hub is actually a 10/100Base-T switching hub. This is required to interface the 10Base-T Ethernet to the 100Base-T Ethernet network. Increasingly, Fast Ethernet becomes a viable option for devices that offer Ethernet. Both the DEC Alpha and the PowerPC will provide Fast Ethernet for the CPU network port in later versions.

9.3. Related Works on Wireless ATM

The wireless link is generally grouped into two different types: wireless satellite link and wireless terrestrial link. Both links typically have higher Bit Error Rate (BER) and more dependent bit errors. In the wireless satellite link, the higher BER is due to the low Signal-to-Noise Ratio (SNR) exhibited by the channel at reasonable transmitter power. The forward error correction coding (e.g., convolutional codes with Viterbi decoding) can be used to reduce the BER at the available SNR. In the wireless terrestrial link, the higher BER and burstiness are caused by channel fading. Again, the FEC coding-interleaving scheme can be considered.

9.3.1. Wireless - Satellite ATM

When ATM traffic is carried over wireless satellite links in commercial and military satellite systems, a number of problems arise. The major problems and issues are as follows:

- ATM protocols were designed for fiber-based switch links. ATM protocols assume that the transmission medium has a very low Bit Error Rate (BER) of 10^{-12} or less and that bit errors occur randomly. Most satellite and wireless links have much worse BER (10^{-6} to 10^{-8}) and errors tend to occur in long bursts, especially when Viterbi coding is used in the Modem.

- An ATM cell carries a 5-Byte header that includes address tags such as virtual path and virtual channel identifiers that are used to route ATM cells. This header includes a 1 Byte Header Error Control (HEC) that can correct single-bit errors in the cell header but only detect multiple bit errors. ATM switches typically discard cells with detected, uncorrectable bit errors. Multiple bit errors that are not detected cause misrouting of ATM cells. There is no provision for correcting bit errors in the cell payload field. While this scheme works well over high-quality fiber links, it does not work over wireless links. The header error correction mechanism is useless in the satellite and terrestrial wireless environments.

- Unlike fiber links, the satellite links have BERs that tends to fluctuate (10^{-3} to 10^{-8}) over time, depending on atmospheric conditions. Typically, the satellite links are designed for the worst case conditions, although the BER tends to remain low for a large portion of the time. Forward Error Correction (FEC) parameters are fixed for the worst-case link analysis. This results in a large loss of usable bandwidth.

- The available bandwidth over satellite links is limited and the cost of bandwidth is high. ATM has a large overhead per cell and is not particularly efficient in its utilization of transmission bandwidth. Techniques to maximize ATM throughput over the limited bandwidth satellite link are desirable.

The demonstration of ATM links over satellite includes numerous testbeds using geosynchronous satellites between fixed ground stations. Examples include programs sponsored by U.S. DoD, European RACE, NASA ACTS, and various private testbeds sponsored by COMSAT, Eutelsat, Telesat, and others. Most of the known communications between ground stations to date has been done using the satellite in a "bent-pipe" configuration where the satellite simply acts as a relay point between the two end stations.

At Boeing, there are several ongoing satellite programs which include Teledesic (known as 'Internet-in-the-sky'), Airborne Information Services (AIS), and DoD's annual demonstrations such as Joint Worrier Interoperability Demonstration (JWID) and

Expeditionary Force Experiment (EFX). The JWID97 demonstration involved data/video transmission from the ground station to a single platform (SPECKLED TROUT) via satellite. The ground-to-air data rate was 1.544 Mbps via a relaying Ku-band satellite and the air-to-ground transmission date rate was 4.8 Kbps via the INMARSAT satellite. The ATM switches used were the Yurie Systems' LDR-50 ATM access concentrator. Using the Ku-band we have built up an ATM satellite simulation testbed (Figure 9.3.1). The goal of the testbed is to demonstrate a transmission of ATM wireless traffic over a simulated satellite channel between two fixed stations and, in the future, between mobile stations.

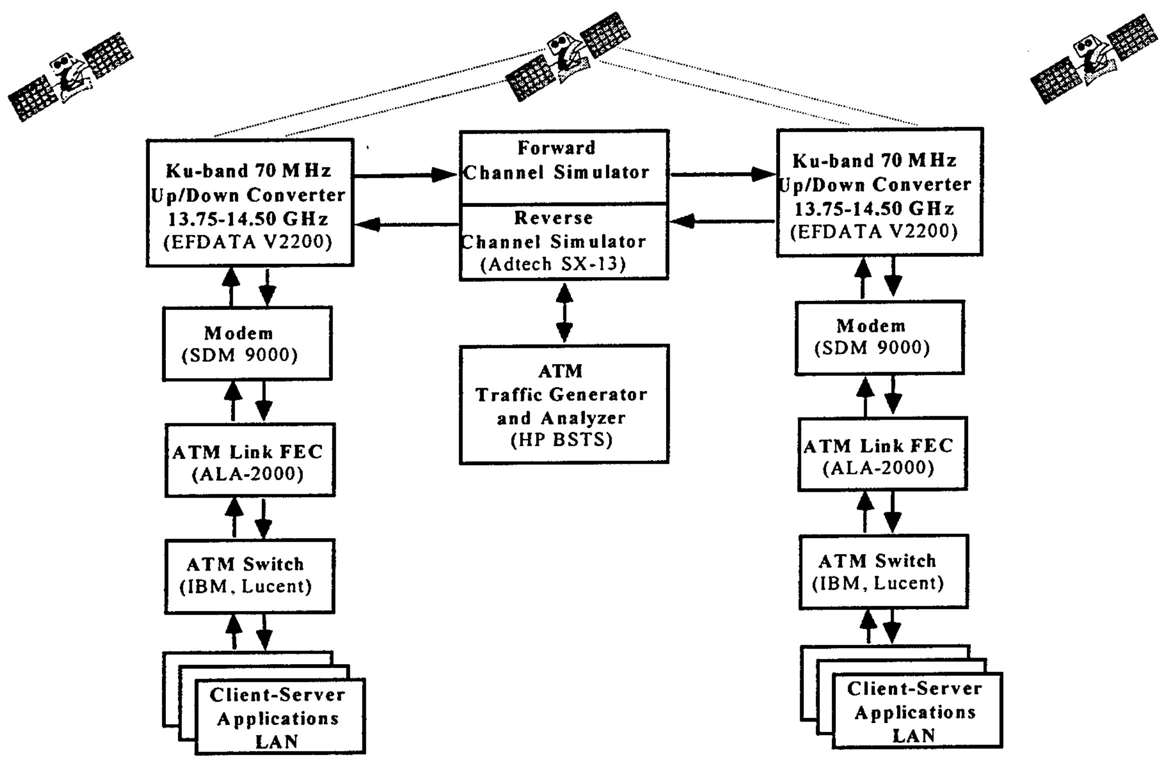


Figure 9.3.1: ATM Satellite Network Simulation Testbed

9.3.2. Wireless - Terrestrial ATM

The advent of wireless ATM technology is intended to provide a direct extension of the core ATM network and services. However, the realization of wireless ATM presents a number of technical challenges that need to be resolved. First, there is a need for the allocation and standardization of appropriate radio frequency bands for broadband communications. Second, new radio technology and access methods are required to operate at high speed. Third, location management must be capable of tracking mobile terminals as they move around the network. Fourth, handoff algorithms must be capable

of dynamically reestablishing virtual circuits to new access points while ensuring in sequence and loss-free delivery of ATM cells. Finally, wireless ATM should provide uniformity of end-to-end quality of service guarantees. Providing such guarantees, however, is difficult during periods of limited bandwidth, time-varying channel characteristics, and terminal mobility.

The ATM Forum created (in 1996) a Wireless ATM (WATM) working group to extend ATM technology to the wireless and mobile domain. During the same time the FCC announced the allocation of 350 MHz of National Information Infrastructure (NII) SUPERNet spectrum in the 5-GHz band. This announcement, with spectrum-sharing rules linked to high-speed wireless access, opens the way for the future deployment of cost-effective radio access to the next-generation Internet and broadband ATM-based networks. The inherent challenge of wireless ATM is to provide ATM, a connection-oriented protocol developed specifically for a reliable high-bandwidth wired infrastructure, along with its negotiated quality-of-service, for mobile users with frequent breaks and makes of connections over a shared, unreliable, and limited-bandwidth wireless medium.

A number of experimental wireless ATM testbeds, developed by NEC, ORL, NTT, and Lucent Technologies, have been instrumental in promoting the idea of wireless ATM. NEC has recently completed the second generation of their prototype, which operates at 8 Mbps in the 2.4-GHz ISM band. The experimental hardware consists of laptops with radio ATM interface cards, multiple VME/i960 processor-based Access Points (AP), and mobility-enhanced local area 2.4 Gbps ATM switches. A dynamic Time-Division Multiple Access/Duplex (TDMA/TDD) medium access control provides explicit support for Constant Bit Rate (CBR), Variable Bit Rate (VBR), and Available Bit Rate (ABR) services over the air interface.

At Boeing, several programs are ongoing related to extending ATM protocol to the wireless environment. The wireless ATM testbed is one example. Using the ISM frequency band at 5.7 GHz, we have built up broadcast stations, using COTS equipment, for communicating point-to-point over a range of up to 40 miles depending on the antennas used. The end stations consist of an ATM switch and associated end user workstations, ATM link accelerator (enhanced error correction and congestion control), CSU/DSU (remoting the modem/antenna from the switch via industry standard Telco T-1 line), and wireless spread-spectrum modem. The goal of this testbed is to demonstrate transmission of ATM wireless traffic between two fixed stations and later between mobile stations. Follow-on work using this testbed will involve substituting Boeing's electronically-steered Phased-Array Antennas (PAA) for the COTS conventional antennas for demonstration of TDMA-partitioned wireless ATM traffic.

9.3.3. Wireless - Mobile ATM

With the development of ATM as a leading protocol for wired broadband networks, along with the growing interests on mobile networking, it is natural that wireless or mobile

extensions of the ATM protocol be considered. The introduction of wireless access and mobility features into a fixed ATM infrastructure can provide the seamless end-to-end broadband connectivity to mobile end-users. Considerations of ATM mobility to date have focused primarily on applications with the mobility of end-user terminals; the ATM switches are fixed while the end-user terminals are mobile. Another class of applications deals with the mobility of the ATM switch itself, where a network segment consisting of one or more ATM switches are in motion with respect to the fixed portion of the network. An example of this application involves mobile platforms with multiple users on-board, such as airplanes.

Boeing has been leading the industrial effort to develop a mobile platform wireless ATM technology in collaboration with IBM through the ATM Forum Wireless ATM (WATM) workgroup. Boeing has demonstrated the concept of mobile ATM communications over satellite through DoD's 1997 Joint Worrier Interoperability Demonstration (JWID97) and the Air force's 1998 Expeditionary Force Experiment (EFX98) demonstrations (Figure 9.3.3).

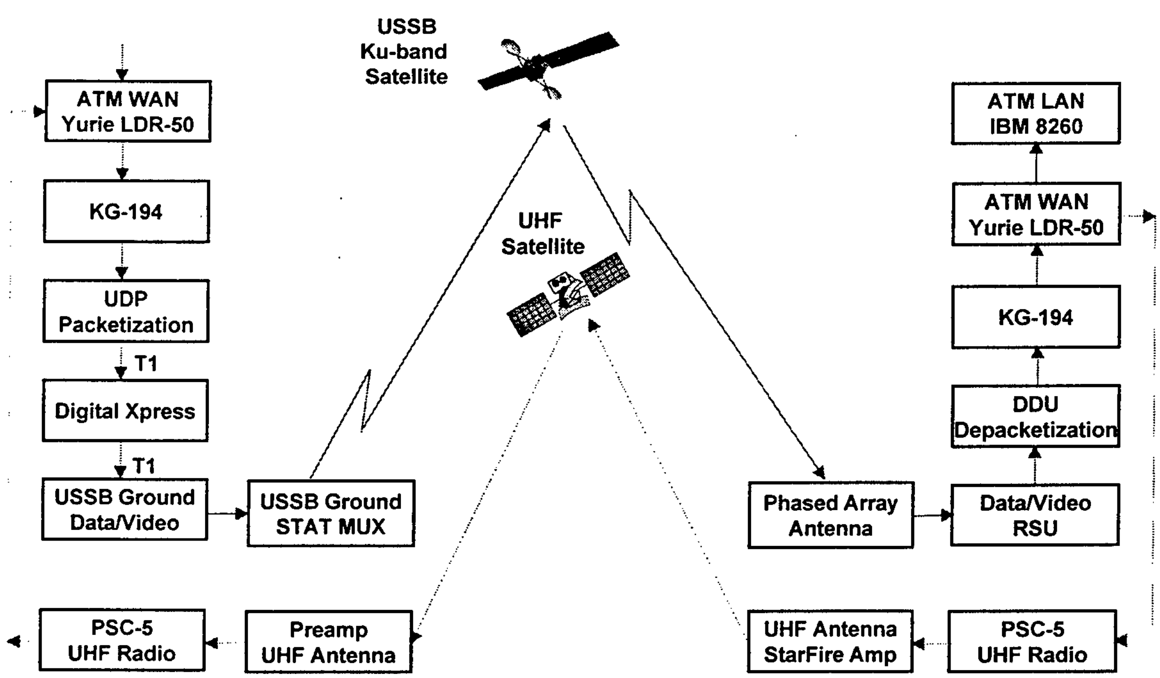


Figure 9.3.3: Simplified System Configuration of EFX98 Demonstration

Boeing has also demonstrated mobile platform ATM hand-over concepts at the Defense Information Systems Agency (DISA). At the IEEE 1998 MILitary COMmunications conference (MILCOM'98) in October 1998, a variety of applications (e.g., collaborative virtual worksharing) were demonstrated on top of the ATM hand-over concept.

EFX98 Demonstration: The EFX98 demonstration involved data/video broadcast from the ground station to multiple mobile platforms via a relaying satellite. The ground-to-air data rate was 1.544 Mbps via a relaying Ku-band satellite and the air-to-ground transmission date rate was 4.8 kbps via UHF satellite. The Yurie Systems' LDR-50 ATM access concentrator was used for ATM WAN switch and an IBM 8260 multiprotocol N-way switch was used for the ATM LAN switch. The ATM network interface cards were either products from FORE Systems or Sun Microsystems. The end stations were SUN Ultrasparc II-xi workstations running Solaris 2.5.1 and Pentium II-400 PCs running NT 4.0. The on-board LANs were 155 Mbps ATM and 10/100 Mbps Ethernet. In the EFX99 demonstration, Boeing's airborne electronically-steered Phased-Array Antenna (PAA) transmit unit may be deployed for air-to-ground transmission as well as the existing capability of receiving ground-to-air wireless ATM traffic.

ATM Handover Demonstration: The goal of the ATM handover testbed is to study the impact of hand-over on multimedia applications while the mobile platform is moving from one satellite footprint to another. The demonstration system consists of two satellite RF links from an airborne mobile platform to each of two ground stations. The two ground switches were connected by an ATM link at 25 Mbps. The two satellite links between the mobile platform on-board switch and the two ground switches were simulated by two T-1 links at different RF frequencies. The move of the platform from satellite footprint-1 to satellite footprint-2 was simulated by manually tuning the two RF link attenuators. The hand-over process and the delay time were investigated while running a variety of applications. Three types of applications were used for tests and demonstrations: FTP/MFTP data/video transfer, remote video-on-demand, and video teleconferencing. The actual applications are PictureTel's Live 50, Starburst's Multicast FTP (MFTP) with a user client interface, Microsoft's Windows Explorer, Media Player, NetMeeting and White-boarding. The end stations were Win95 PCs with Pentium 166 or higher processors. Depending on the tests, each PC had a Real Magic MPEG-1 or MPEG-2 hardware decoder card. The ATM switches were the IBM 8285 workgroup switches with T-1 expansion modules and Multiprotocol Switching Services (MSS) module that functions as an ATM LANE server. The PC's network interface cards were the PCI 25 Mbps ATM from IBM or FORE Systems.

9.3.4. Issues and Future Works

The WATM working group is currently focusing on two major tasks that include specifications for mobile ATM and the radio access layer. The specification of mobile ATM deals with suitable extensions to the existing specifications for location management, handoff, routing, addressing, and traffic management. The specification of the radio access layer addresses the physical layer, medium access control, data link control, and radio resource control. The major thrust of the working group includes the following issues of addressing architecture, mobility, location management, and radio access.

Architecture: Two approaches are under consideration; one is an integrated model, which incorporates all mobility and radio functions into the ATM switch, and another is an access model, which offloads some functions (e.g., radio resource control) from the switch to the access point. The first approach places more complexity in the switch while the latter approach requires a new access point control protocol to convey messages between the access point and the ATM switch.

Handoff Signaling: The aim of handoff signaling is to enable wireless terminals to move seamlessly between access points while maintaining connections with their negotiated Quality of Service (QoS). The proposed handoff algorithm under consideration by the working group is a backward handoff through the old access point.

Location Management: Two schemes are under consideration. One integrates location management with ATM signaling, and the other partitions the address space, keeping location management external to existing signaling. Existing location management solutions (e.g., GSM, IS-41 MAP, mobile IP) are also being investigated.

Radio Access: The Broadband Radio Access Network (BRAN) project by the European Telecommunications Standard Institute (ETSI) is currently developing broadband radio local loops and other radio access systems operating at data rates of 25-155 Mbps. The WATM and BRAN working groups are jointly developing the radio access layer specification.

The common issues in wireless ATM and mobile networks include, but are not limited to, the connection and location management, routing, and hand-over. Although the broad issues of mobility may remain the same, the solution for the wide-area mobile network segments with many fixed end-users will differ from that of the mobile terminals in a local-area network environment. One example is the impact of mobile ATM technology on satellite and ad hoc networking. The major impact of these technologies on ATM is the need for a mobile PNNI link. Relatively little work has been done in this area. IBM is currently developing jointly with Boeing a mobility extension to the PNNI routing protocol applicable to mobile ATM network technology.

10. SUMMARY AND CONCLUSIONS

The basic objective of the ATM technology investigations, which are described herein, was to develop an ATM network for advanced airborne C4I applications, and then demonstrate that network in as realistic and stressing an environment as possible. The most realistic airborne C4I environment available, short of a very expensive airborne test and demonstration, was the AWACS Open System Architecture (OSA) prototype system in the Boeing's Integrated Technology Development Laboratory (ITDL). The OSA system was being developed as a candidate standard for the mission avionics architecture for future advanced C4I platforms, particularly for retrofits to existing E-3s and for an Advanced AWACS. The scenario selected for the demonstration, Joint Suppression of Enemy Air Defenses (JSEAD), had already been established and was well rehearsed. The demonstration would be conducted with operators in the loop; the ATM network would replace the OSA baseline backbone network, which was (at the time) a combination of FDDI and Ethernet. A successful live demonstration of ATM in support of the OSA system in a stressful airborne C4I scenario would then help lay the groundwork for the application of ATM technology in near-term and evolving airborne C4I programs, such as the Advanced AWACS.

Interpretation of Data and Conclusions:

Development and demonstration were completed and were highly successful, and further illustrated that the basic requirements for an Advanced AWACS could be met with networks based on ATM technology. The ATM network was evaluated and tested extensively, and demonstrated performance fully acceptable for an advanced C4I aircraft. Performance equivalent to the combined FDDI and Ethernet was demonstrated, and stress testing of the network indicated that significant reserve capability was available.

Significant technical details, particularly on interoperability between various venders' products and multicast design options, were developed during the course of the design, implementation, and subsequent testing. This information, reported herein, is available as the basis for future efforts and, further, has been of great value in related efforts such as wireless ATM development and the Air Force's Expeditionary Force Experiment (EFX) program support.

The ATM architecture development, while not without a few problems, was accomplished on schedule and without great difficulties. A great deal of information about ATM technology was accumulated. While the ATM technology is maturing at a rapid pace, it is not yet as mature as older networking technologies with which it is often compared, such as Ethernet. We had a few problems, as noted in the body of the report, but, as with any technology at this stage in the development, a few growing pains remain. While ATM is a very complex and evolving technology, the effort here establishes that it is sufficiently mature at this time to be highly successful in airborne applications. The interoperability and standardization issues described indicate that we still need to go through the system integration and testing process. However, the ATM networking

technology is sufficiently mature to be viable for airborne C4I applications with very little risk.

Future C4I Aircraft Architectures:

The investigation illustrated the versatility and robustness of ATM to an extent unexpected at the start of the program. It was assumed, as we began, that the OSA architecture would become a widely used standard, and that this architecture would be simply repeated in the various airborne C4I programs then under way in parallel. Several programs did, in fact, select ATM as an onboard network during the course of this effort, but, interestingly each chose (and was able) to optimize its particular design based on their own detailed requirements, and the expected OSA standard was, in fact, not adhered to. Examples include:

- Advanced AWACS OSA Program: ATM, Ethernet (Redundant)
- US AWACS Extend Sentry Step 1 Program: Fibre Channel
- NATO AWACS Midterm Program: Gigabit Ethernet
- EFX98 Program: ATM, Ethernet (Redundant)
- Wedgetail Program: Fast Ethernet
- NIMROD Program: Fast Ethernet (Redundant)

This situation further reflects the very rapid pace of the ATM technology developments, and the flexibility and breadth of the products now available. The ability to develop an architecture simply and quickly with COTS products makes a standard architecture unnecessary and possibly even cumbersome.

The program reported here had its greatest success in support of the EFX demonstrations. This success validated the efforts reported herein as being a significant step forward in the development of ATM for C4I aircraft. Originally, ATM was viewed by the EFX program as having relatively high risk. Further, the ATM on-board systems planned were supposed to be only a back-up to Ethernet. Through our demonstration, ATM was, instead, accepted by the program as the primary aircraft on-board LAN for the mission avionics systems. We were also able, based on our work, to demonstrated that ATM was sufficiently mature to be accepted onto the EFX airborne C4I platforms a year ahead of the original schedule, in EFX98 rather than EFX99. Also interesting was the development and fielding of distinctive and different network architectures for the three demonstration platforms equipped with ATM for EFX98. These were the TS-3, E-3 AWACS, the JFACC (Joint Forces Air Component Commander) aircraft, and the EOC (Enroute Operations Center) aircraft.

Recommendations for Future Efforts:

Significant advances in ATM technology development for airborne C4I applications are being achieved and transferred at a rapid pace, particularly in the commercial technology arena. However, areas where future efforts could make significant contributions include:

a) Development of small ruggedized ATM switches, specifically for aircraft applications.
b) Continued evolution of the commercial ATM standard to include mobile networks.
c) Continued wireless ATM technology development.
d) Development of complex networking functionality for airborne networks.
e) Further development of multicast applications.
f) Development of designs and applications for nonsymmetrical networks.
g) Continued development and commercialization of high-gain phased array antenna technology.

Also in the planning stages are significantly more complex demonstrations under the auspices of the EFX program. The wide area ATM effort from EFX98 will be expanded by the Air Force in 1999, but not to the extent we had originally planned. A significant number of SATCOM and networking issues (which are not trivial) were identified in the EFX98 design studies and during the experiments. The EFX98 exercise was the first time multiple aircraft were networked together (via TCP/IP), rather than simply receiving broadcasting in an ATM format. We believe that attempts were made to work the JFACC, the EOC, the TS-3 AWACS, and perhaps a JSTARS, all as a network. We proposed demonstrating a full-up ATM network for 1999, but the Air Force would not accept the risk. We are now shooting for the year 2000 exercise.

The wide area wireless (SATCOM) networking technology area is, therefore, where significant follow-on effort to the current work done to date is very badly needed. We must solve the wide area wireless (SATCOM) ATM/IP networking and related satellite communications problems, and further demonstrate to the Air Force that we can build a network that will work effectively. The necessary ATM test and evaluation laboratory is set up and running, thanks to Rome Laboratory. We should, in a follow-on effort, define, analyze, design, and build wide area network components and related software, and test and demonstrate them in the laboratory – much as was done under this Rome Laboratory contract. This follow-on effort would then transition directly into the EFX2000 for flight testing with multiple airborne platforms.

APPENDIX A: Data Exploitation, Mission Planning, and Communications System

The data exploitation, mission planning, and communications (DEMPC) system (Figure A.1) provides collection, processing, storage, display, and control functions in support of target search and tracking systems such as SAR. The DEMPC system has been developed under Government contract and Boeing IR&D funding. Boeing is a first-tier subcontractor to provide DEMPC system hardware and software in support of the ground control stations (GCS) of the Tactical Endurance - Unmanned Aerial Vehicle (TE-UAV) Advanced Concept Technology Demonstration (ACTD) for Tier-II UAVs. Specifically, the DEMPC system provides the following functions:

a. Mission planning.
b. Mission monitoring.
c. EO/IR display.
d. SAR sensor/SGP status display.
e. Map display.
f. Aircraft location data map display.
g. Hardcopy printout.
h. Airborne VCR and SAR sensor payload control.
I. Interface to external JDISS system.
j. Interface to external Trojan Spirit System.
k. Conversion of RS-170 imagery to National Imagery Transmission Format (NITF).
l. Video recording in National Television Standards Committee (NTSC) format.
m. Payload imagery freeze frame.
n. Digital payload data storage.
o. Payload data annotation.

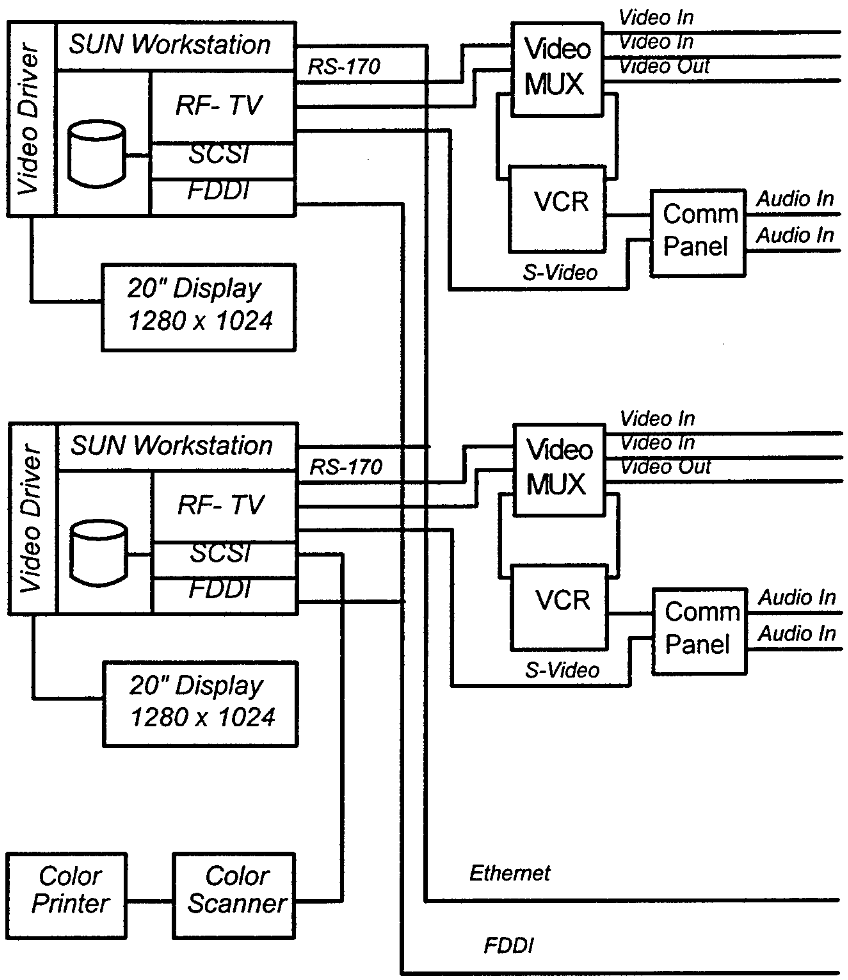


Figure A.1: DEMPC System Block Diagram

APPENDIX B: Published Paper in IEEE MILCOM'98 Conference Proceeding

ATM NETWORK-BASED INTEGRATED BATTLESPACE SIMULATION
WITH MULTIPLE UAV-AWACS-FIGHTER PLATFORMS

Jae H. Kim,* *Senior Member, IEEE,* James M. DeFilipps, Nicholas P. Impert, Charles F. Derheim, Michael Y. Thompson, and Sankar Ray, *Member, IEEE*

Boeing Information, Space & Defense Systems
P.O. Box 3999, MS/3W-51, Seattle, WA 98124-2499
(253) 657-7685 (TEL), 657-8903 (FAX)

and

Richard C. Butler II

US Air Force Research Laboratory, Rome Research Site
Rome, NY 13441-5700

Abstract

We demonstrated an integrated battlespace simulation on Advanced AWACS prototype network, supporting realistic C^4I applications such as real time battle management, SAR image processing and analysis, and air tasking order monitoring. In this paper, we will first describe an integrated battlespace simulation and its demonstration scenario, then the ATM testbed for integrated battlespace simulation in both ATM LAN Emulation and Classical IP over ATM multicast configurations. Finally, we will describe the network performance test (with netperf and nttcp benchmark tools) and the application performance test (with AWACS mission computer program and display console program) of FDDI, ATM LAN Emulation, and Classical IP over ATM networks.

Introduction

The C^4I platform (e.g., AWACS) plays a major role in battlespace management. A future C^4I platform will require an advanced mission avionics architecture to meet increased information processing requirements of future missions. The implementation of such advanced mission avionics and the simulation of advanced C^4I aircrafts in the battlespace are under study at Boeing. The battle management systems are simulated in the ATM network environment with the multiple highend workstations representing hardware-in-the-loop. The simulation sequence consists of video images from

* Point of Contact E-mail: jae.h.kim@boeing.com

the sensor image simulation laboratory (UAV Ground Station) to the battlespace management station (Advanced AWACS) where it is processed and disseminated to the fighter aircraft displays (Advanced Fighter Dome). In this paper, we will describe an Integrated Battlespace Simulation (IBS) supporting realistic C^4I applications; real time battle management, SAR image processing and analysis, and real time air tasking order (ATO) monitoring. Then, we will describe ATM testbed for integrated battlespace simulation and benchmark performance test of the network and Advanced AWACS application programs.

Integrated Battlespace Simulation

Integrated Battlespace Simulation [1] includes the unmanned aerial vehicle (UAV), C^4I platform, and fighter aircraft as core battlefield components. The entire sequence of battlespace management from off-board sensor, via C^4I platform, to fighter aircraft is simulated with multiple SUN Sparc, DEC Alpha, and SGI Onyx workstations, all interconnected with an ATM OC-3 network (Figure 1). The raw image sensor data is taken from a predetermined fixed location of the Image Generator (simulated airborne UAV). This video frame data is captured by an SGI Onyx video processor, stored into a video frame buffer, and processed into a realistic synthetic aperture radar (SAR) image at the SUN Sparc-20s (simulated UAV Ground Stations). Then, the video frame buffer is transferred to multiple DEC Alpha-600s (simulated Advanced AWACS platforms) and DEC Alpha 500 for Toshiba large flat panel display screen. The video frame buffer is also transmitted with additional commanding information to the SGI Onyx-2 in a Fighter Dome (simulated Advanced Fighter) along with voice communications between the AWACS and Fighter. The information is then displayed in the fighter's cockpit for use as a target information.

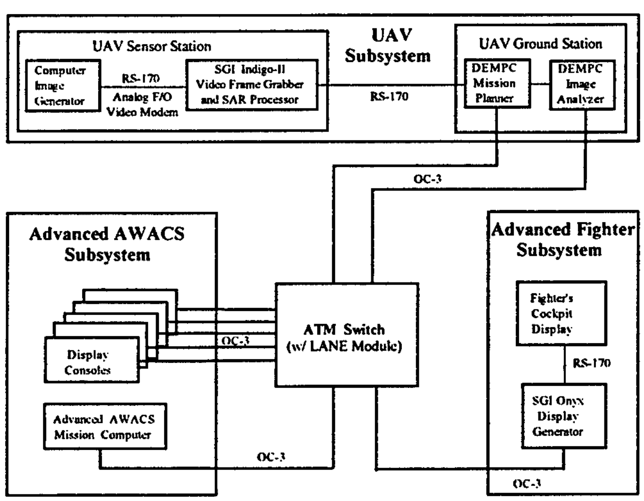


Figure 1: Integrated Battlespace Simulation

Demonstration Scenario of Integrated Battlespace Simulation

The battlespace simulation demonstration scenario is derived from the Joint Suppression of Enemy Air Defense (JSEAD) program. It involves a conflict between two regional powers which has evolved into an active combat situation. The allied forces are deployed in the area supporting in a defensive coalition. The demonstration events occur during the early days of the conflict, and depict JSEAD activities leading to the achievement of air supremacy. Within this environment, enemy forces can generate counter-air actions (air-to-air, surface-to-air) and also capable of conducting land, air and naval combat operations. The demonstration scenario covers the following major phases of activity [1]:

(1) Allied air forces are conducting coordinated attacks against enemy air defense assets and associated command and control elements as the preliminary step toward achieving air superiority in theater.
(2) AWACS uses the off-board resource data as well as on-board sensors to detect and target threat emitters, and initiates strike operation with available assets.
(3) Advanced Fighters engage threat emitter sites.
(4) AWACS coordinates follow-on activities against other enemy fighter aircrafts.

Prior to start of simulation, some Surface-to-Air Missile (SAM) threats have been suppressed during an initial wave of JSEAD strikes. Defensive fighters have been pushed up to counter any enemy retaliatory strikes, including cruise missile strikes launched from ground, surface and air platforms. At the time of simulation start (t=to), AWACS has been on station for several hours. AWACS has an established air picture that shows the fighters (tracks with ID), a special point for the air defense unit, a KC-135 tanker orbiting to the theater (optional) and ingress fighters on Air Tasking Order (ATO)-directed JSEAD missions. The major events that occur over time in the scenario are as follows.

Start of Scenario: The threat SAM sites surviving initial JSEAD strikes continue activity.
Event 1: Fighter positioned about hundred miles from targets.
Event 2:SA-10 SAM target begins operation with sporadic, intermittent emission pattern.
Event 3:AWACS identifies new threat emitter, retasks airborne UAV, and plans for strike.
Event 4: AWACS identifies threat emitter and diverts ATO-directed fighter.
Event 5: AWACS notifies Joint Force Air Component Commander (JFACC) of action and monitors strike.
Event 6: Ground UAV Controller uplinks SAR image of enemy SAM site to AWACS.
Event 7: The fighters receive divert tasking and SAR image of target from AWACS, conduct strike, and commence egress from enemy airspace.
End of Scenario: AWACS detects enemy fighters reacting to strike.

ATM Battlespace Simulation Testbed

The core battlespace components are simulated with the multiple, disparate platforms on ATM network testbed shown in Figure 2; AWACS for DEC Alpha-500/600 workstations

running Unix 4.0 on PCIbus, UAV for SUN Sparc-20 running Solaris 2.4 on Sbus, and Fighter for SGI Onyx-1 (Onyx-2) running Irix 5.3 (Irix 6.4) on VMEbus (PCIbus).

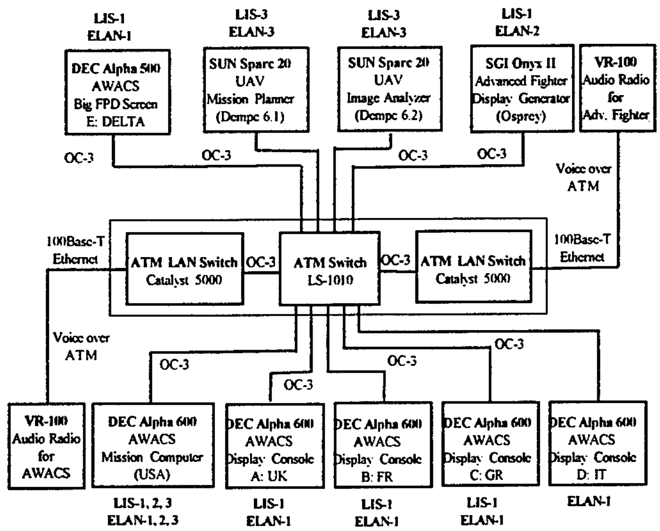


Figure 2: ATM Network Testbed for IBS

The C^{4}I platform (e.g., AWACS) requires a network that is capable of simultaneous unicast and multicast for data distribution. The TCP/IP unicast is used for operator-related activities between AWACS Mission Computer and Display Consoles. The UDP/IP multicast is used for common data broadcasting to all display consoles within a multicast group on a periodic basis. Unlike a connectionless legacy LAN technology, the multicast capability is not easy to implement in a connection-oriented ATM technology [2]. The ATM multicast configuration details used for the integrated battlespace simulation network can be referred to Ref. [1, 3].

ATM Multicast Configuration

There are potential approaches to address the ATM multicast problem in the legacy LAN environment, for example, multipoint-to-multipoint VPC (virtual path connections), a multicast server, or overlaid point-to-multipoint connections. However, the multipoint-to-multipoint VPC requires a protocol to allocate unique VCI values to all nodes in the multicast group and such a mechanism does not currently exist. The multicast server requires a point-to-multipoint connection with all nodes as well as a point-to-point unidirectional connection from each node to a multicast server. The overlaid point-to-multipoint connections requires each node to maintain the total number of all connections within each group. Thus, there is no ideal solution yet for ATM multicast [2]. The existing "Classical IP over ATM (CIP)" protocol supports neither broadcast nor multicast, while the ATM LAN Emulation (LANE) protocol supports only a broadcast. The higher

layer protocols for ATM IP multicasting (e.g., MARS, MPOA, PIM) are under development [4].

ATM Classical IP-based Multicast Solution: The ATM Classical IP (CIP) protocol lacks a broadcast (multicast) mechanism. We resolved this broadcast (multicast) problem of ATM Classical IP with a simple configuration solution. The simple solution is to set up point-to-multipoint permanent virtual circuit (PVC) connections (Multicast_PVC) from a broadcast server to all clients. Since there is no such server in CIP, we create a virtual broadcasting node (that corresponds to a broadcast service access point) at the switch. The procedure to configure this CIP broadcast (multicast) mechanism will be described in detail elsewhere [3].

ATM LAN Emulation-based Multicast Solution: ATM LANE can support multiple independent emulated LANs (ELANs), and the membership in any of the ELANs is independent of the physical location of the end system. For the integrated battlespace simulation, four different ELANs were set up to support the ATM multicast groups; ELAN-1 (AWACS Display Consoles subnet), ELAN-2 (Fighter subnet), ELAN-3 (UAV subnet), and ELAN-4 (Voice over ATM subnet). The AWACS Mission Computer must be a member of all ELANs so that it can selectively broadcast information to any of the AWACS, Fighter, or UAV group as different multicast groups. It should be noted that the CIP (or LANE) intrasubnet protocol works only within its own logical IP subnet (or ELAN), thus a separate router is required for communications between different logical subnets (or ELANs) [5].

Network Benchmark Test

The netperf and nttcp were used for performance benchmarking test of ATM-based networks. Netperf [6] allows to measure various aspects of network performance, focusing on bulk data transfer throughput (bandwidth) and request-response (latency) tests for TCP and UDP. Nttcp is a benchmark tool for determining TCP and UDP performance between two systems. Nttcp times the transmission and reception of data between two systems using the UDP or TCP protocols and it tests the bulk transfers with variations of number of buffers and sizes. All tests were performed in three network configurations; FDDI, ATM LANE, and ATM Classical IP. The most common test is to measure bulk data transfer performance (throughput) in either a TCP stream or a unidirectional UDP stream. Figure 3 shows a TCP_STREAM throughput test performance. The maximum throughputs in the TCP_STREAM test of FDDI, ATM LANE, and ATM CIP were 96 Mbps, 108 Mbps, and 118 Mbps, respectively, over variable message size. The throughput increased with the receive and transmit socket buffer size but it is relatively insensitive to the message size when it is bigger than maximum transmission unit (MTU).

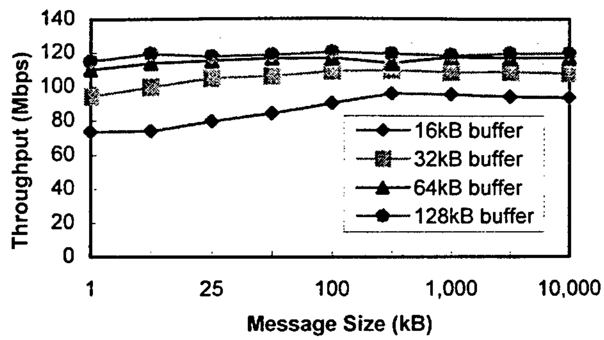


Figure 3(a): ATM CIP TCP Throughput

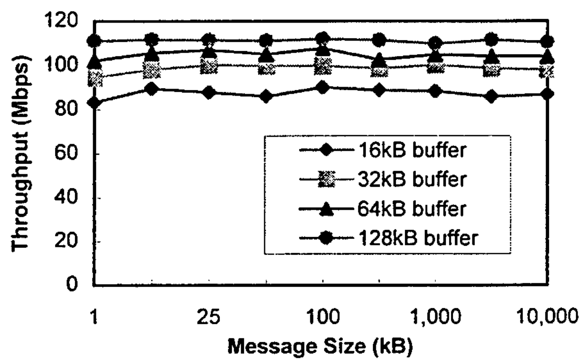


Figure 3(b): ATM LANE TCP Throughput

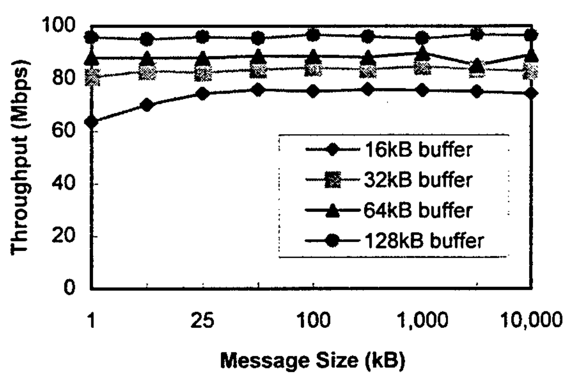


Figure 3(c): FDDI TCP Throughput

The second test is to measure a transaction rate performance. A transaction is defined as the exchange of a single request and a single response (RR). The round-trip delay can be

estimated from a transaction rate; with a 1 KByte message, 0.63 ms (FDDI), 0.58 ms (ATM LANE), and 0.60 ms (ATM CIP), all for TCP traffic. Figure 4 shows TCP_RR test results.

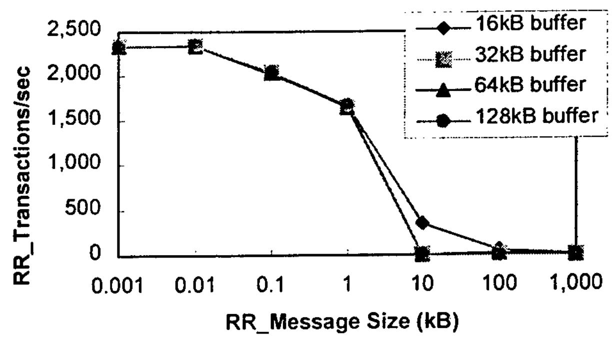


Figure 4(a): ATM CIP TCP_RR Performance

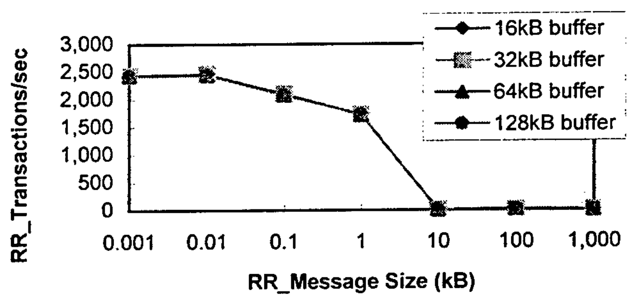


Figure 4(b): ATM LANE TCP_RR Performance

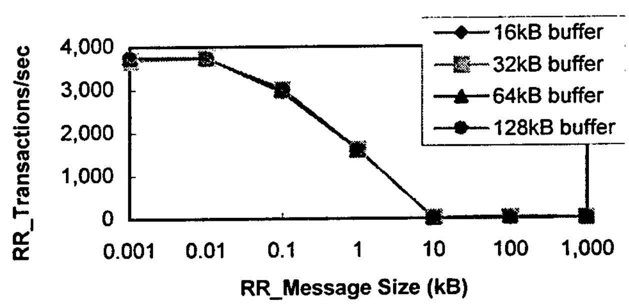


Figure 4(c): FDDI TCP_RR Performance

The UDP stream performance test is similar to a TCP stream test. The one difference is that the transmit size can not be larger than the smaller of the local and remote socket buffer size. A UDP_STREAM test in Figure 5 shows that FDDI can handle better than

ATM irrespective of socket buffer size. Even with the transmit size constraint, it still may need to control the interval between packets to keep UDP_STREAM from running away with all the resources of the ATM network. Note that the delay between sending packets was not counted in this UDP throughput test; this can be a subject for further study.

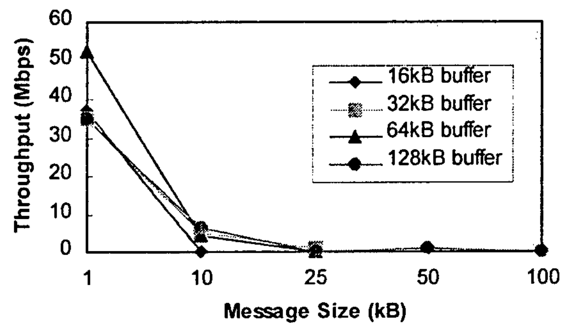


Figure 5(a): ATM CIP UDP Performance

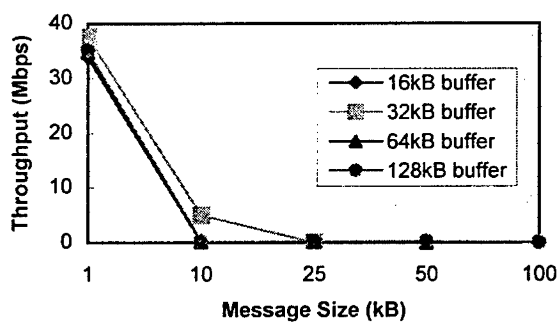


Figure 5(b): ATM LANE UDP Performance

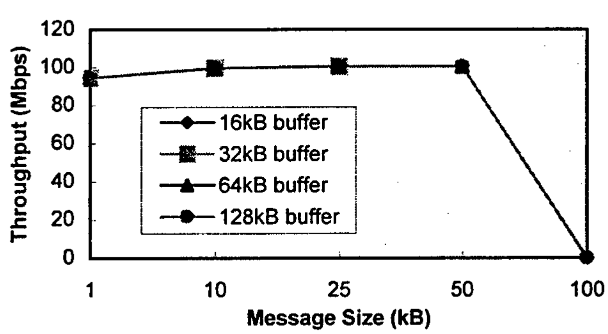


Figure 5(c): FDDI UDP Performance

The UDP transaction rate performance is shown in Figure 6. Similarly, the average round-trip delay can be estimated from a transaction rate; 0.61 ms for UDP in all cases with a 1 KByte message.

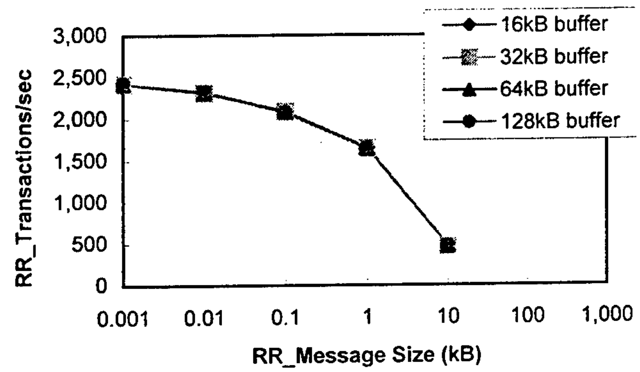


Figure 6(a): ATM CIP UDP Transaction

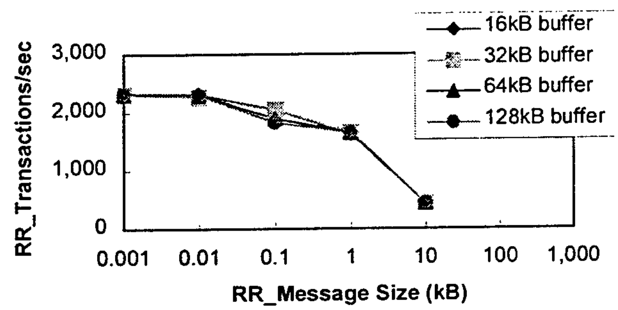


Figure 6(b): ATM LANE UDP Transaction

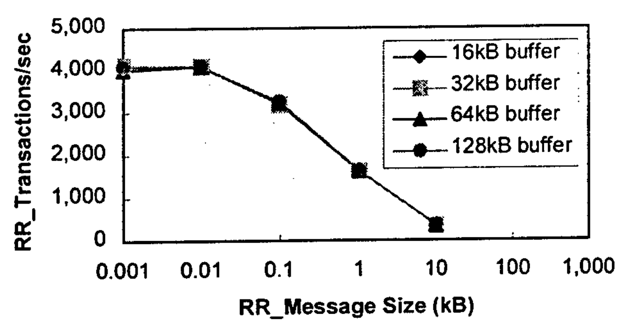


Figure 6(c): FDDI UDP Transaction Rate

Besides the separate TCP and UDP unicast tests, since a real AWACS application requires TCP unicast and/or UDP multicast, it is interesting to test the performance of (a) TCP or UDP multicast, (b) simultaneous TCP unicast and UDP unicast, and (c) simultaneous TCP unicast and UDP multicast. However, it should be noted that the UDP

multicast and the simultaneous TCP and UDP multicast tests are not easily implemented with network benchmark tools [7]. They are tested only by running actual AWACS application programs as described in the next section. The one way for us to closely simulate the scenarios above is running multiple copies of netperf at the same time. Figure 7 shows an example of TCP multicast test by sending a TCP_STREAM test message to all destinations (a.k.a, TCP-All) at the same time.

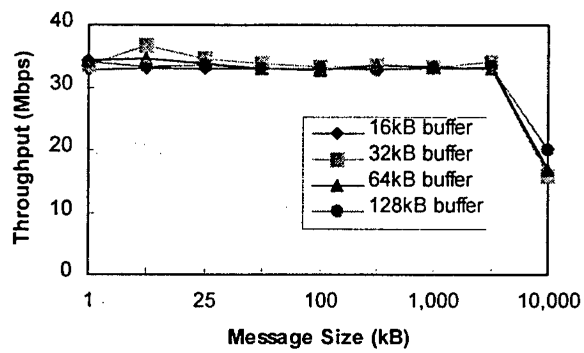


Figure 7(a): ATM CIP TCP-All Performance

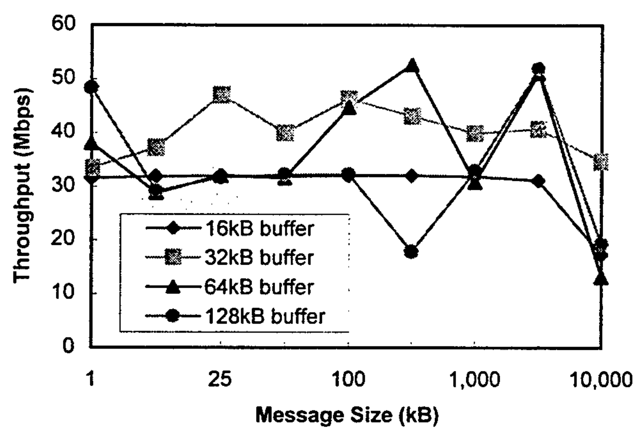


Figure 7(b): ATM LANE TCP-All Performance

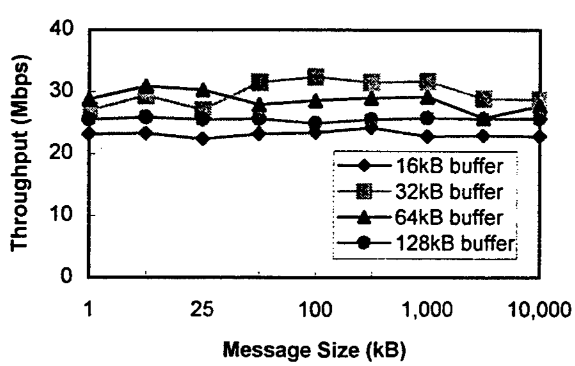


Figure 7(c): FDDI TCP-All Performance

Figure 8 shows a test example of the FDDI network in the simultaneous TCP and UDP stream. The test script with multiple copies of netperf commands allows to run TCP and UDP streams at the *almost* same time. It is worth while to mention that these tests (Figures 7 and 8), based on a special test script with multiple netperf commands, need more study for the validity.

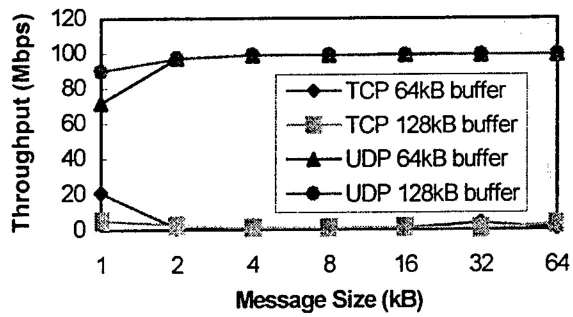


Figure 8: FDDI Simultaneous TCP and UDP_STREAM Performance

Application Benchmark Test

The application performance test was performed with the Advanced AWACS mission computer program (MCP) and display console program (DCP). The C^4I platform system loading can be a large number of simulated targets, sensor returns (Radar or IFF returns), and active tracks. The maximum number of 3,000 tracks and simulated targets were generated in this IBS demonstration. Sensor returns were then generated internally by the AWACS Mission Computer. Once the number of simulated targets have been generated, the automatic track initiation will be started and the tracks generated off the simulated sensor returns. This information is continuously transmitted to the AWACS Display Consoles to observe the simultaneous TCP unicast and UDP multicast performance of the Advanced AWACS application running over each network.

Table 1 shows a test summary of Advanced AWACS application with a 3,000-track-simulation that requires transmission of simultaneous TCP unicast and UDP multicast over the network. The AWACS application program was modified for this test, so that the socket buffer size could be changed at a running time. Test results showed that all networks had various problems associated with a mission computer program and/or database transmit problems below a buffer size of 32kB. The MCP problems include the occasional disconnect/reconnect, shutdown, or radar returns disappear of simulated target data. The database transmit problems are meant by that various databases do not get transmited, i.e., either no target, point objects, or no tracks get updated. Above 64kB, the FDDI and ATM CIP showed normal operation, while ATM LANE also showed mostly normal with an occasional panic problem; the display consoles running AWACS programs occasionally enter a panic mode [8] and automatically rebooted.

Socket Buffer Size	FDDI Multicast	ATM CIP Multicast	ATM LANE Multicast
1-4 kB	MCP Down Database Transmit Poblem	MCP Down Database Transmit Poblem	MCP Down Database Transmit Poblem
8 - 32 kB	Database Transmit Poblem	Database Transmit Poblem	Database Transmit Poblem
64 kB	Normal	Normal	Normal, but Panic Poblem
128 kB	Normal	Normal	Normal, but Panic Poblem
512 kB	Normal	Normal	Normal, but Panic Poblem
1500 kB	Normal	Normal	Normal, but Panic Poblem

Table 1: Simultaneous TCP Unicast and UDP Multicast AWACS Application Performance with 3,000 Tracks Simulation.

Summary

We demonstrated an integrated battlespace simulation with an ATM network testbed. The ATM testbed was configured for multicast using ATM Classical IP and ATM LAN Emulation. Then, the network and application performance was compared among three different network configurations of FDDI, ATM LAN Emulation, and ATM Classical IP.

Acknowledgments

The authors thank R. Gilde and A. Ayyagari for valuable discussions, the ITDL staff for running an Integrated Battlespace Simulation program, and the ITDL management for ATM-AWACS program support. The work described in this paper was sponsored by the US Air Force Research Laboratory, Rome Research Site.

References

[1] Jae H. Kim, "Demonstration of ATM-Based AWACS Network with Integrated Battlespace Simulation," Draft Final Technical Report, US Air Force Research Laboratory Contract No. F30602-96-C-0212, July 1998 (in preparation).

[2] D. Minoli and A. Alles, LAN, ATM, and LAN Emulation Technologies, Artech House, 1996; See also D. Ginsburg, ATM: Solutions for Enterprise Internetworking, Addison-Wesley, Harlow, England, 1996.

[3] J.H. Kim, M.Y. Thompson, S. Ray, and R.C. Butler II, "A Simple Multicast Configuration with Classical IP over ATM: Performance Comparison with ATM LANE," June 1998 (in preparation for IEEE Communications Letters).

[4] G.C. Sackett and C.Y. Metz, ATM and Multiprotocol Networking, McGraw-Hill, 1997.

[5] The emerging intersubnet protocols (e.g., NHRP, MPOA) will allow for direct communications among different logical subnets (or ELANs).

[6] Netperf: A Network Performance Benchmark (Rev. 2.1), Hewlett-Packard, February 1996.

[7] Private communications with Rick Jones (Hewlett-Packard) on the netperf.

[8] The panic mode problem displays the error messages such as "kernel memory fault" or "freeing free mbuf".

APPENDIX C: Published Paper in the IEEE Communications Letters (1999)

A Simple Multicast Configuration with "Classical IP over ATM": Performance Comparison with FDDI and ATM LAN Emulation

Jae H. Kim,* *Senior Member, IEEE,* Michael Y. Thompson, and Sankar Ray, *Member, IEEE*

Phantom Works, Boeing Information, Space & Defense Systems
P. O. Box 3999, MS 3W-51, Seattle, WA 98124-2499

and

Richard C. Butler II

US Air Force Research Laboratory, Rome Research Site
Rome, NY 13441-5700

ABSTRACT

An integrated battlespace simulation, consisting of an off-board sensor, an airborne C^4I platform, and a fighter aircraft, was performed over an ATM OC-3 backbone network interconnecting multiple, disparate processing platforms (i.e., SUN Sparc-20s, DEC Alpha-500/600s, and SGI Onyx-1/Onyx-2). A multicast capability is required to run a realistic battlespace simulation program over ATM network. However, it is not supported by the existing protocols (e.g., Classical IP over ATM). A simple solution that addresses the ATM Classical IP multicast problem is described in this paper. The network and application performance of ATM Classical IP is then compared with that of FDDI and LAN emulation.

I. INTRODUCTION

The integrated battlespace sensor-to-shooter sequence, from an off-board sensor (e.g., unmanned air vehicle - UAV), via an airborne C^4I platform (e.g., airborne early warning and control system - AWACS), to a fighter aircraft, was simulated in an ATM environment with multiple platforms, all interconnected with an ATM OC-3 network. Raw image sensor data was first taken from a predetermined fixed location of an Image Generator, processed into a realistic synthetic aperture radar (SAR) image at SGI Indigo-2 (simulated airborne UAV), and analyzed at SUN Sparc-20s (UAV ground station). The SAR image was then transferred to multiple DEC Alpha-600s (C^4I platform) for evaluation, and then transmitted to SGI Onyx-2 (F-15 fighter dome) with the additional information provided by the C^4I platform. The SAR image and the C^4I information was

* E-mail address: jae.h.kim@boeing.com

then displayed on the fighter's cockpit for use as a target information [1, 2]. The integrated battlespace simulation network requires both point-to-point (unicast) and point-to-multipoint (multicast) capability for command, control, and information dissemination. Unicast, based on the TCP/IP protocol, is used for operator-related activities between the C^4I mission computer and display consoles. Multicast, based on the UDP/IP protocol, is used for common data broadcasting to all display consoles within a multicast group on a periodic basis.

II. ATM MULTICAST CONFIGURATION

A multicast capability is not trivial to implement in the connection-oriented ATM networking technology. There are potential approaches to address the ATM multicast problem in the legacy LAN environment; multipoint-to-multipoint virtual path connections, a multicast server, or overlaid point-to-multipoint connections. An ideal solution is not yet available [3]. The existing ATM LAN Emulation (LANE) protocol supports only a broadcast and the classical IP over ATM (CIP) protocol does not support broadcast nor multicast. The higher layer protocols for ATM IP multicast (e.g., MARS) are under development [4]. We implemented a simple solution to the multicast problem of ATM Classical IP and compared its network and application performance with that of FDDI and ATM LANE. The integrated battlespace simulation ATM testbed consists of multiple platforms; AWACS for DEC Alpha-500/600 workstations running Unix 4.0 on PCIbus, UAV for SUN Sparc-20 running Solaris 2.4 on Sbus, and Fighter for SGI Onyx-1 (Onyx-2) running Irix 5.3 (Irix 6.4) on VMEbus (PCIbus). ATM switches used for the testbed were Cisco Systems' LS-1010 and Catalyst 5000. ATM adapters were FORE Systems' PCA200EUX for PCIbus, SBA-200E for Sbus, and VME-200 for VMEbus [5].

ATM LAN Emulation-Based Multicast: ATM LANE can support multiple independent emulated LANs (ELANs), and the membership in any of the ELANs is independent of the physical location of the end-user. Four different ELANs were set up for the simulation to support the ATM multicast groups; ELAN-1 (AWACS Display Consoles), ELAN-2 (Fighter), ELAN-3 (UAV) and ELAN-4 (Vioce over ATM). The AWACS mission computer that plays a key role of command, control, and information dissemination to multiple ELANs, must be a member of all ELANs so that it can multicast (i.e., selectively broadcast) information to any of the AWACS, Fighter, and UAV multicast groups.

ATM Classical IP-Based Multicast: The ATM Classical IP protocol lacks a broadcast (multicast) mechanism. The simple solution is to set up point-to-multipoint permanent virtual circuit (PVC) connections (Multicast_PVC, hereafter) from a broadcast server to all clients. However, there is no such a server in the current CIP protocol. We have to create a virtual broadcasting node (that corresponds to a broadcast service access point) within the switch. The procedure to configure a CIP multicast is described in details as follows:

1. Configure an ATM interface (qaa0) for a standard "Classical IP over ATM" with an appropriate ATMARP server address, operating over switched virtual circuit (SVC) connections.
2. Create a point-to-multipoint permanent virtual circuit (PVC) node (Multicast_PVC) within an ATM switch using unique vpi/vci number for each multicast group, i.e., AWACS, Fighter, and UAV multicast groups. This Multicast_PVC virtual node serves as a broadcast access point.
3. Create a virtual IP address for the Multicast_PVC virtual node. Note that a unique IP subnet address should be assigned to each multicast group when multiple multicast group subnets are required.
4. Configure a new ATM interface (qaa1) for a CIP Multicast_PVC virtual node at both the host and the client workstations with a proper virtual IP address. Repeat the process for the multiple subnets, as required.
   - **ifconfig qaa1 <host station multicast IP address> netmask 255.255.255.0** at a host station
   - **ifconfig qaa1 <multicast_PVC virtual IP address> netmask 255.255.255.0** at all client stations
5. Bind IP addresses to the unique vpi/vci numbers at a host workstation and multiple client workstations, such as
   - **atmarp -c <multicast_PVC virtual IP address> qaa1 <vpi> <vci> <revalidate>** at a host station
   - **atmarp -c <host station multicast IP address> qaa1 <vpi> <vci> <revalidate>** at all client stations
6. Make the final configuration (e.g., atmarp) persistent across reboots by writing a start-up script as necessary.
7. Run a standard "Classical IP over ATM" on top of "Multicast_PVC" virtual node connections.

This permits the simultaneous transmission of point-to-point TCP unicast traffic over SVC, and point-to-multipoint UDP multicast traffic over multicast_PVC. Figure 1 shows the ATM CIP multicast configuration that allows for selectively broadcasting to the battlespace groups.

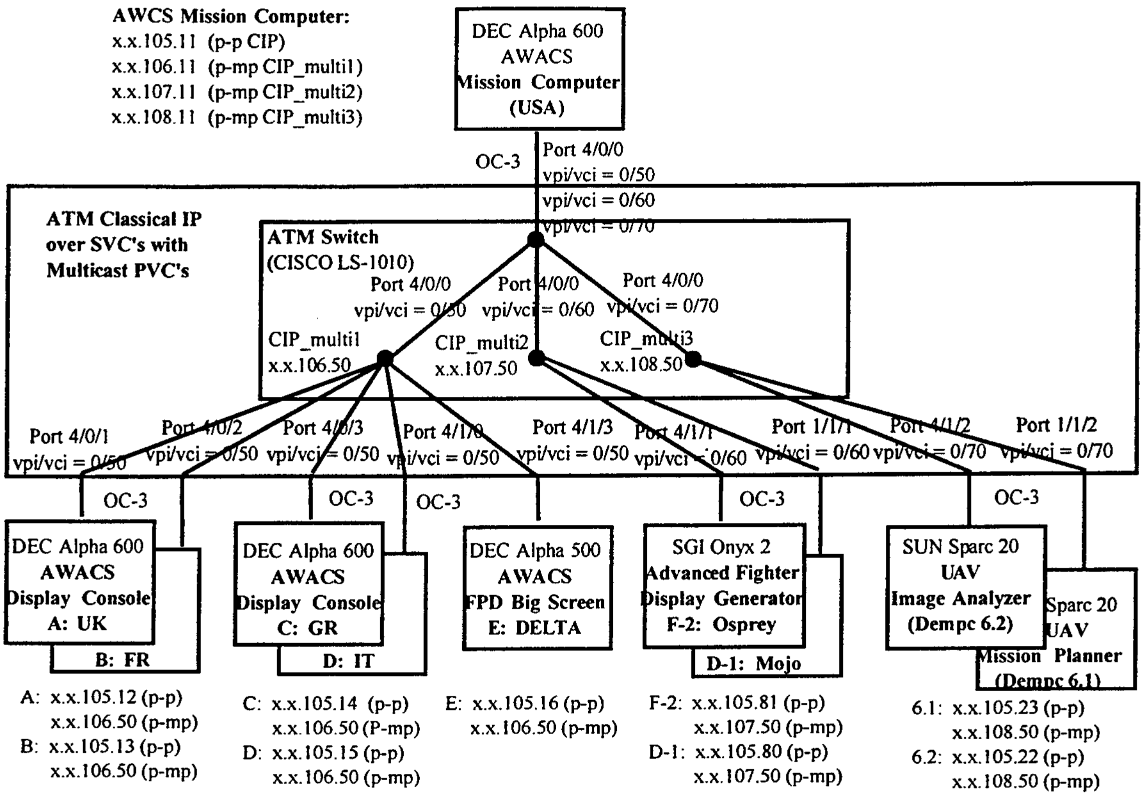


Figure 1:ATM Classical IP Multicast Configuration using Point-to-Multipoint PVCs

III. NETWORK AND APPLICATION PERFORMANCE TEST

The ATM LAN emulation was configured first and evaluated as a baseline reference point. The overall performance and scalability of the ATM LANE network is affected by its broadcast and unknown server (BUS). A multicast throughput required for advanced C^4I platform (a minimum 40 Mbps multicasting data to multiple display consoles) also depends on the LANE BUS. Then, the BUS throughput was tested by measuring a broadcast forwarding rate over the ATM ELAN [6]. Figure 2 shows the BUS throughput as a function of the maximum transmission unit (MTU). For the worst-case MTU of 64 Byte, the BUS throughput of ~60 Mbps (in Figure 2) is considered to be the upper limit.

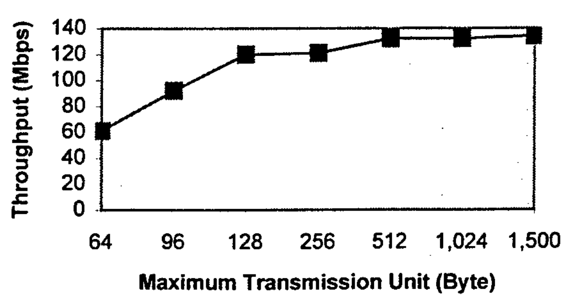


Figure 2: ATM LANE BUS Throughput

Network Benchmark Test: The network benchmark tool, Netperf [7], was used for performance test and comparison among three network configurations; FDDI, ATM LANE, and ATM Classical IP. The most common network benchmark test is to measure bulk data transfer performance (throughput) and transaction rate (latency) for a bidirectional TCP stream or a unidirectional UDP stream. The maximum throughput in TCP_STREAM test of FDDI, ATM LANE, and ATM CIP was 96 Mbps, 108 Mbps, and 118 Mbps, respectively, over a variable message size. The TCP_STREAM throughput (Figure 3) increased with the receive and transmit socket buffer size, but it was relatively insensitive to the message size when the message size was bigger than the maximum transmission unit (MTU).

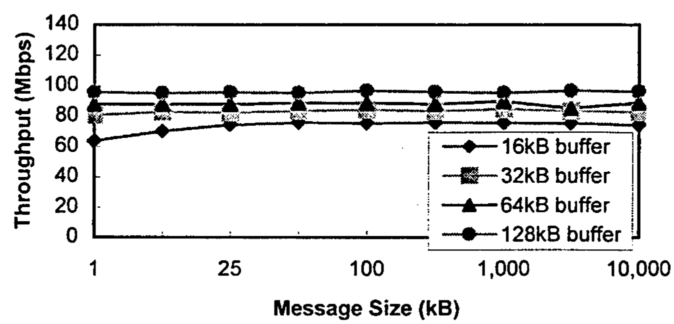


Figure 3(a): FDDI TCP Throughput

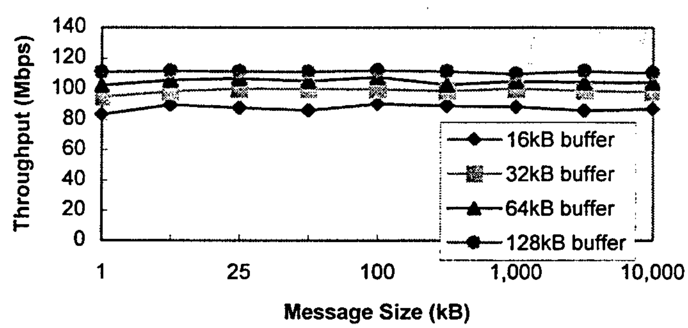


Figure 3(b): ATM LAN Emulation TCP Throughput

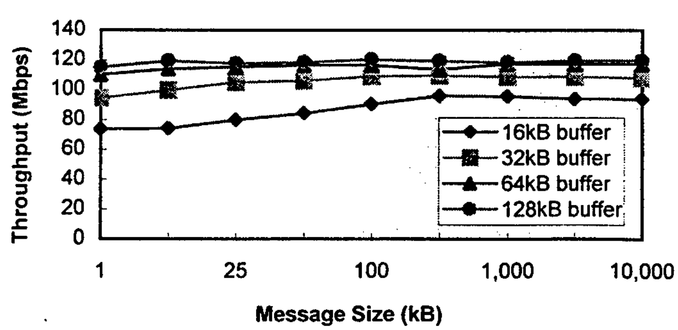


Figure 3(c): ATM Classical IP TCP Throughput

The UDP_STREAM test showed that FDDI could handle UDP traffic better than the ATM LANE or Classical IP, irrespective of a socket buffer size, as shown in Figure 4.

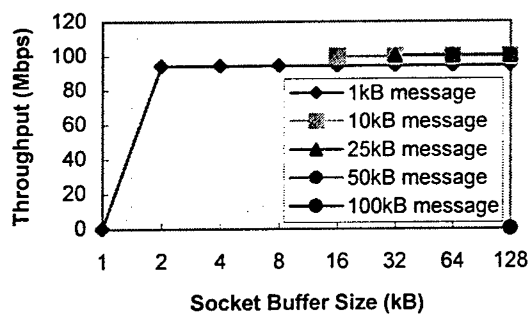


Figure 4(a): FDDI UDP Throughput

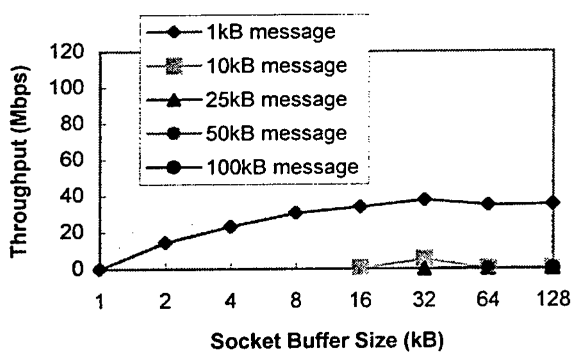


Figure 4(b): ATM LAN Emulation UDP Throughput

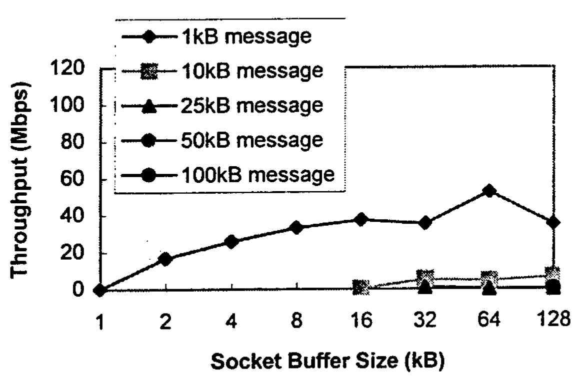


Figure 4(c): ATM Classical IP UDP Throughput

The UDP_Request/Response (RR) transaction rate was tested (Figure 5). A transaction is defined as the exchange of a single request and a single response. The round-trip average latency can be inferred from the transaction rate; with a 1 KByte message, 0.63 ms for FDDI, 0.58 ms for ATM LANE, and 0.60 ms for ATM CIP, all for TCP; and 0.61 ms in all cases for UDP. Then, the round-trip delay gets longer as the message size gets larger. The detailed tests will be described elsewhere [1].

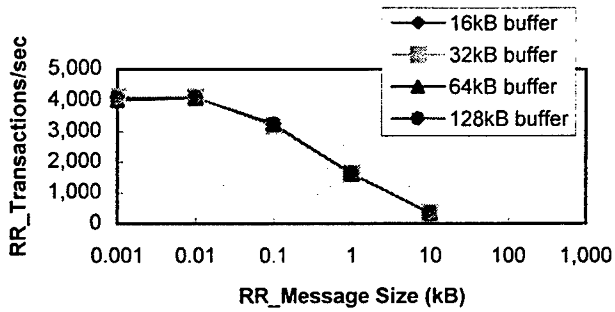


Figure 5(a): FDDI UDP_RR Transaction Rate

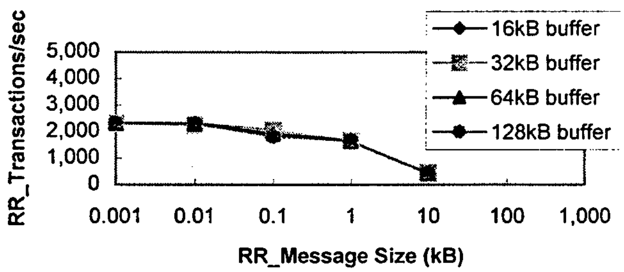


Figure 5(b): ATM LAN Emulation UDP_RR Transaction Rate

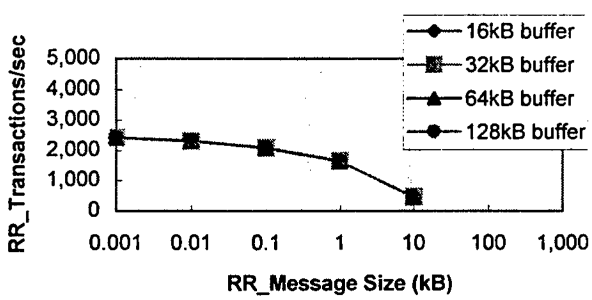


Figure 5(c): ATM Classical IP UDP_RR Transaction Rate

Application Benchmark Test: The application test was performed with AWACS mission computer and display console programs. The C^4I platform system loading can be a large number of simulated targets, sensor returns (e.g., radar or IFF returns), and active tracks. The maximum number of 3,000 tracks and simulated targets were created and the

sensor returns were then generated by the mission computer. While the information was continuously transmitted to the display consoles, the simultaneous TCP unicast and UDP multicast performance of the AWACS application was monitored over the variable track and socket buffer size. Test results showed that, below a buffer size of 32kB, all networks had various problems associated with a mission computer program and/or database transmit problems. Above 64kB, the FDDI and ATM CIP showed normal operation, while ATM LANE showed mostly normal except an occasional panic problem; the display consoles running AWACS programs occasionally enter a panic mode [8] and automatically rebooted.

IV. SUMMARY

The integrated battlespace simulation (IBS) was performed over ATM network. ATM multicast configuration with the multiple logical subnets of Classical IP multicast-PVCs and multiple emulated LANs, supporting the IBS network testbed with multiple platforms, was described. The network and application performance was then compared among three configurations of FDDI, ATM LAN emulation, and ATM Classical IP Multicast-PVC networks.

REFERENCES

[1] J.H. Kim, "Demonstration of ATM-Based AWACS Network with Integrated Battlespace Simulation," U.S. Air Force Rome Laboratory Contract No. F30602-96-C-0212, Final Technical Report, Oct. 1998.

[2] J.H. Kim, N.P. Impert, J.M. DeFilipps, C.F. Derheim, M.Y. Thompson, S. Ray, and R. Butler, "ATM Network-Based Integrated Battlespace Simulation with Multiple UAV-AWACS-Fighter Platforms," Presented at MILCOM'98, Bedford, MA, Oct. 18-21, 1998.

[3] D. Ginsburg, ATM: Solutions for Enterprise Internetworking, Addison-Wesley, Harlow, England, 1996.

[4] M. Decina and V. Trecordi, "Convergence Telecommunications and Computing to Networking Models for Integrated Services and Applications," IEEE Proc., vol.85, No.12, pp.1887-1914, Dec. 1997.

[5] The proper ATM adapters were unavailable for the Digital Equipment Corp.'s Alpha-500s hosts; Alpha-500s were incompatible with FORE Systems' existing ATM adapters and were replaced with Alpha-600 workstations for testbed operation.

[6] The LAN switches were used to send a stream of broadcast frames to the BUS, which in turn forwards the frames back to the LAN switches. The broadcast frames forwarded from the BUS were monitored.

[7] Netperf: a network performance benchmark (Revision 2.1), Hewlett-Packard, Feb. 1996.

[8] The panic mode error messages , e.g., "kernel memory fault" or "freeing free mbuf."

☆U.S. GOVERNMENT PRINTING OFFICE: 1999-610-130-81164

MISSION OF AFRL/INFORMATION DIRECTORATE (IF)

The advancement and application of information systems science and technology for aerospace command and control and its transition to air, space, and ground systems to meet customer needs in the areas of Global Awareness, Dynamic Planning and Execution, and Global Information Exchange is the focus of this AFRL organization. The directorate's areas of investigation include a broad spectrum of information and fusion, communication, collaborative environment and modeling and simulation, defensive information warfare, and intelligent information systems technologies.